EFFECT OF HYDROCYCLONE INLET DEVICE (HID) IN THREE PHASE GRAVITY SEPARATOR FOR OIL WATER SEPARATION IMPROVEMENT

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by

Nasuha binti Nazarudin

Dissertation submitted in partial fulfilment of
the requirements for the
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CERTIFICATION OF APPROVAL

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Approved by,

(Mrs. Mazlin bt Idress)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

July 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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NASUHA BINTI NAZARUDIN

ABSTRACT

As the oil production field reaches its mature phase and the surface processing facilities reaches its maximum capacity, more water is produced together with the reservoir fluid. The management and control of water production have become a vital activity in order to enhance the quality of crude oil processing in meeting customer satisfaction. The option that is currently adopted in the oil and gas industry is the introduction of Hydrocyclone Inlet Device (HID) in a gravity separator. This new design takes advantage of both the centrifugal force of HID and gravity force of a gravity separator. The main advantage of this HID is the reduction in foaming of the inlet flow of the gravity separator. By applying HID at the inlet of gravity separator, the rejuvenation of new separator vessel is not required since it is more economical to replace the current inlet with cyclone inlet. The HID helps to increase separation capacity without additional vessel and major modification to the existing facilities. However, for the application of HID in high water cut from oil production field, the mixture of oil and water is of difficult oil-water emulsion pattern. This complex emulsion pattern is caused by the changes in oil-water composition and also different sizes of oil droplets due to the choke variations. The retention time taken by the droplets to coalescence during gravity settling process is affected and this causes the reduction in the efficiency of separator in oil-water separation. Apart from that, this oil and water mixture exhibits different properties at certain operating parameters such as at high temperature, flowrate and oil-water proportion. Therefore, the interest of this project is to investigate the effect of HID in gravity separator at certain parameters. An experimental approach for oil and water separation with constructed prototype using waste crude oil at different operating temperature, flowrate and oil-water proportion is performed in this project to improve the oil-water separation. Results obtained from the experiment shows that the HID performs better at high operating temperature and high incoming fluid flowrate. However, at high water cut, the performance of HID is lesser compared to typical plate diverter, since the swirling action exerted by HID causes more complex reverse water-in-oil emulsion.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 PROJECT BACKGROUND

In the mature offshore producing oil fields, managing water production is an important and critical aspect in separation of oil and gas from reservoir fluid mixture. As the surface processing facilities of the fields has reached its maximum capacity, the installation of new equipments requires new approach. In order to reduce production cost of offshore and marginal fields, the oil and gas industry has shown keen interest in developing a gravity separator with application of centrifugal force at the inlet diverter which is known as Hydrocyclone Inlet Device (HID). Due to the cyclonic effect by this inlet device, a swirl is created at the inlet region and thus, promoting oil water segregation before the settlement of the fluid by gravitational means takes place.

The main characteristic of this inlet device is their high flow capacity which means it could operate at higher fluid throughput. The advantages provided by this HID are:

a) High allowable momentum of fluid (increase in throughputs).
b) Reduction of foam in oil emulsion.
c) Increase the coalescence of oil and water droplets.
d) Enhancement in gas demission.

(Chin et. al, 2002)

As from the real experience cases, the installation of HID in V-1010 separator at Angsi field from Peninsular Malaysia Operation (PMO) of PETRONAS Carigali Sdn, Bhd. (PCSB) has proved that HID helps to increase the separation capacity without additional vessel and major modification to the existing facilities. The cyclonic separation has been proven to increase oil capacity by installing a tangential inlet device into existing vessel. *(Nazarudin, 2005)*

1.2 PROBLEM STATEMENT

An experiment on oil and water separation at oil-water composition of 30%, 50% and 70% of water cut percentages by using gravity separator with plate diverter and separator retrofitted with HID had found that HID can improve the efficiency of oil water separation. The retention time for oil to settle from water is up to 35%. This means a reduction in a certain time required for oil to separate from water by means of gravity after reached its equilibrium phase. The efficiency of HID is also proven in controlling emulsion problem. The emulsion is reduced faster at first minute of separation by up to 50% reduction. HID helped to reduce the emulsion pad thickness at the early stage of separation by enough centrifugal action to overcome surface tension and break down the emulsion. This experiment is conducted at atmospheric pressure and ambient temperature with different of water cut percentages. *(Syafri, 2008)*

However, there are modifications that need to overcome prior to the experiment which are type of fluid used, operating condition (flowrate, temperature and pressure) and the composition of oil and water. Diesel is used in the experiment before instead of crude oil. With different properties in density, viscosity and composition between both fluids, may lead to some changes in the results before. The real operation separator is operated at high temperature and pressure to operate the fluid flow from reservoir which may influence the efficiency of oil-water separation.

Since water cut from each well may keep changing during the production, the reservoir fluid production is controlled and choked accordingly. From this choke variation, it results in different sizes of oil droplets. With different oil and water ratio in the incoming mixture from wells may create a very difficult emulsion pattern of oil and water and affect separation by gravitational settling. Due to this phenomena, Nilsen et. Al, 2007 stated that with proper application of shear force or gravity force may break complex emulsion rather than stabilizing the emulsion as to improve the oil and water separation.

1.3 OBJECTIVES AND SCOPE OF STUDY

The main objectives of this project are:

a) To setup an experiment for oil and water separation using gravity separator retrofitted with HID at different operating parameters.
b) To study the effect of HID at different flow rate, operating temperature and oil-water proportion in improving oil-water separation.

The scope of work in this project is to investigate the effect of HID towards the crude oil and water separation at different flowrate, operating temperatures and oil-water proportion by measuring the thickness of layers formed after the gravity settling. Analyze oil and water retention time taken in oil-water separation process by using HID retrofitted in the gravity separator. The focus of this project is also in the emulsion reduction as to improve separation efficiency of a separator. Analyze the effect of flowrate, pressure and temperature changes towards the cyclonic separation due to the fluid properties differences. Evaluate and compare the HID performance with typical plate inlet diverter.

CHAPTER 2
LITERATURE REVIEW

2.1 MATURE FIELDS

2.1.1 Definition and Element of Mature Fields Development

Mature fields is defined as the petroleum oil or gas fields that reached the peak of their production or when producing fields in declining mode or reached their economic limit after primary and secondary recovery efforts. The indicators of the field's maturity are the increasing water and gas production to the surface, decreasing pressure in the reservoir and the aging of used equipments. Typical production life of field is shown as in the figure 1 below: *(Mature Fields Development: A Review, 93884 – MS)*

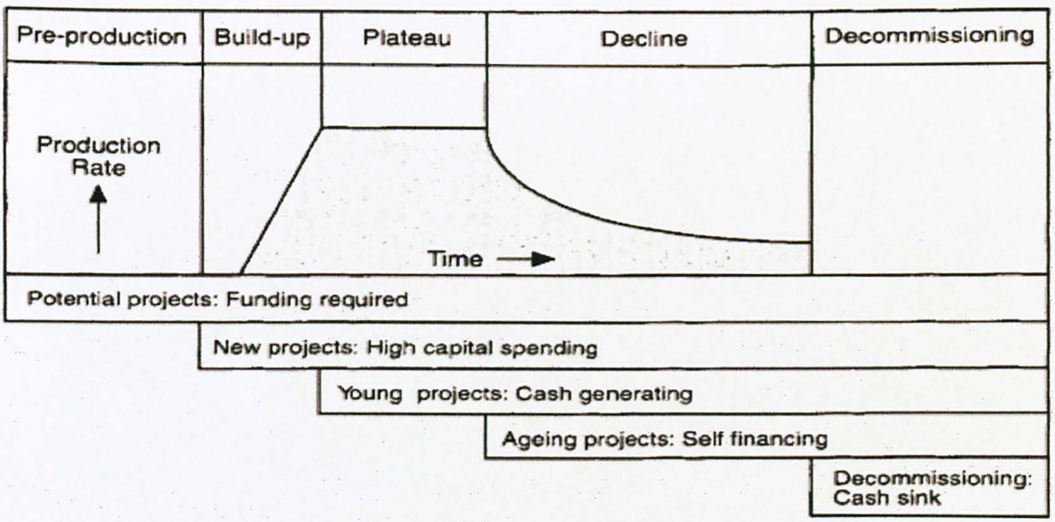

Figure 1: The Field Life Cycle and Simplified Business Model.

As oil and gas fields mature, the produced water cut from wellbore tends to increase. Since there is still a lot of potential in mature wells, some recent advances technology are applied. The main factor that defines how effective such technologies in the mature fields are their ability to improve the water cut in these wells. *(Ed Heiberger, 2009)*

2.1.2 Produced Water from Production of Crude Oil

Naturally the formation rocks are generally permeated with fluids such as water (brine), oil or gas. When hydrocarbons are produced, they are brought to the surface as a produced fluid mixture. This water is frequently referred to as "connate water" or "formation water". It becomes produced water when it is produced to the surface with the crude oil or natural gas and the amount is increasing during field mature phase.

Produced Water Characteristic

The physical and chemical properties of produced water vary considerably depending on the geographic location of the field, the geological formation, and the type of hydrocarbon that being produced. Produced water properties and volume can even vary throughout the lifetime of a reservoir. *(John A. Veil et Al, 2004)*

Constituents in Produced Water

Table 1: List of Constituent in Produced Water.

No	Constituent	Effect to Environment / Operation
1	Dispersed Oil	Can create potentially toxic effects near the discharge point. Soluble organics and treatment chemicals in produced water decrease the interfacial tension between oil and water.
2	Dissolved or soluble organic compound	Contributors to produced water toxicity. **Reduced pH can disturb the oil/water separation process** and can impact receiving waters when discharged
3	Treatment	Posing the greatest concerns for aquatic toxicity include

	chemicals	biocides, reverse emulsion breakers, and corrosion inhibitors.
4	Produced solids	Can cause the well or produced water treatment system to shut down and influence produced water fate and effects. The fine-grained solids can reduce the removal efficiency of oil/water separators, leading to high amount of oil and grease limits in discharged produced water.
5	Bacteria	Can clog equipment and pipeline and also form difficult-to-break emulsion.
6	Scale	Can clog flow lines, form oily sludge that must be removed, and form emulsions that are difficult to break. Example: calcium carbonate, calcium sulfate, barium sulfate, strontium sulfate, and iron sulfate

(John A. Veil et Al, 2004)

As mentioned the above, most of the produced water constituents may affect both environment and oil and gas production operations and it becomes main priority for the oil and gas operators nowadays to separate water from the oil produced at first before through the processing and marketing stage.

Produced Water Management Options

Among of the produced water management options is to keep water from the wells such as using mechanical blocking devices and water shut-off chemicals and another options is to keep water from getting to the surface by using Downhole Oil/Water Separators (DOWS).

Most of mechanical blocking devices used such as straddle packers, bridge plugs, tubing patches, cement and many more have been used for many years but do not work well in all applications. For injecting the chemicals to the formation deep in the earth where they are unlikely to affect the biosphere, they have a beneficial impact since the gel polymer treatment used in this method extended the least economic life at least seven years. However, this application required several ingredients and treatments involved are formed after the where it gives **higher economic cost which are only preferable for higher producing fluid wells.** *(John A. Veil et Al, 2004)*

The Downhole oil/water separators (DOWS) as shown in the figure 2 below are a relatively new technology that can help reduce water handling costs and produce more hydrocarbons to the surface per day. Features critical for success include a high water-to-oil ratio, the presence of a suitable injection zone that is isolated from the production zone, compatible water chemistry between the producing and injection zones, and a properly constructed well with good mechanical integrity. However, DOWS installations are **expensive and not cost effective for all wells.** *(Tom Godbold et Al, 2000)*

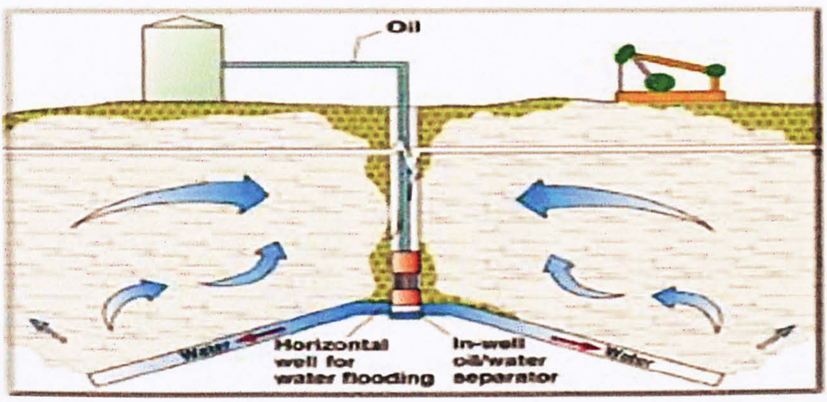

Figure 2: The Illustration of Downhole Oil/Water Separators (DOWS).

2.2 SURFACE SEPARATION PROCESS

2.2.1 Oil Production Facility

An oil facility is a collection of equipment at the surface that is used to separate the fluids (oil, gas or water/brine) that come out of an oil or gas well into separate streams that can be sold and sent to a gas plant or refinery for further processing. The typical oil facility is shown in the figure 3 below.

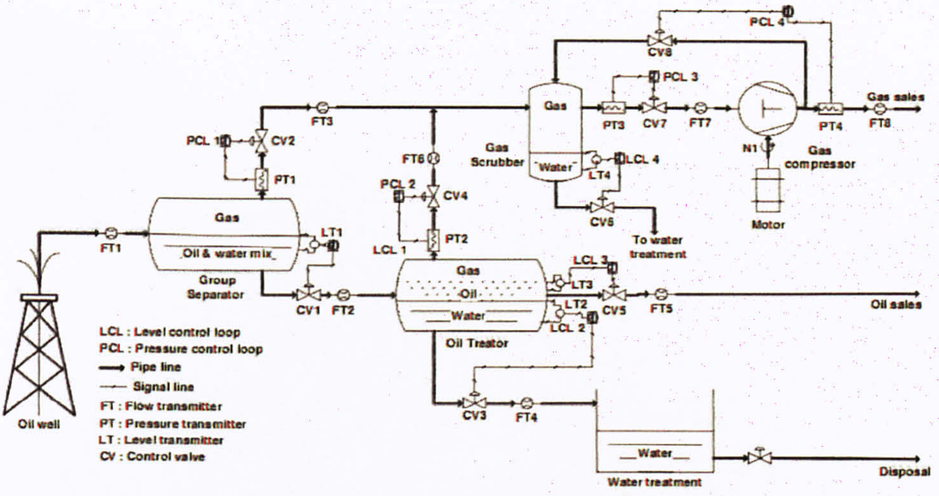

Figure 3: The Oil Production Facility Schematic Diagram. (*Atalla F.Sayda et.Al)*

The importance of this separation are for stage recovery of liquid hydrocarbons, producing saleable oil and gas streams, well testing, metering, and protection of pumps and compressors as to increase the sustainability of the equipments itself. A few types of separating vessel that applied in the petroleum production surface facilities are such as oil/gas separator, liquid knockout vessel, gas scrubber, flash chamber, and filter.

The general summary of primary functions of an oil and gas separator along with separation methods is shown as in the Table 1 below:

Table 2: Internal Devices and Separation Aids for Separators.

Function	Method of Separation	Internal Devices and Separation Aids
Separation of oil from gas	Gravity	Mist extractors: impingement type; change of direction type; cyclones, filter cartridges; and washing
Separation of gas from oil	Gravity	Cyclones, plate packs, matrix packs, agitation, heat
Separation of water from oil	Gravity	Cyclones, plate packs, matrix packs, agitation, heat

Separation of oil from water	Gravity	Cyclones, plate packs, matrix packs, agitation, flotation
Separation of solids from liquids	Gravity	Cyclones, agitation, heat, flotation

(Mary Thro et. al, 2007)

As shown in the above table, separation of water and gas from oil in general is using gravity force as a method of separation together with internal devices of a separator. The internal device is used as to enhance or accelerate the gross separation process at the inlet section of separator. Among of suggested internal device is such as cyclones which have been as the main interest in this project.

2.2.2 Separation of Oil, Water and Gas

When reservoir fluids are produced to the surface, it is main necessary to segregate the oil, gas, and water into separate streams to maximize salable product and typically is accomplished by gravity separation in a horizontal or vertical separator. Free water which produced together with oil is defined as water that is separated from oil by gravitational settling. A common type of separator for this purpose is known as a **free-water knockout FWKO) or also be known as three phase separator**.

This FWKO are installed downstream from the separators when the wells produce large volumes of free water. Knockouts are usually horizontal pressure vessels providing adequate retention time for free water to drop out of the emulsion. Oilfield emulsions are usually water-in-oil emulsion which can be broken in the surface facilities by several processes:

- Applying Heat (Heater Treaters)
- Chemicals
- Retention (Water Knock Outs)

(Fike Corporation)

2.3 THREE PHASE GRAVITY SEPARATOR

Gravity separators are commonly used in the oil and gas industry for separation of hydrocarbon fluid (oil and gas) and water by means of gravitational settling. This separator can be classified into two types:

a) Two-phase separators, which are used to separate gas from oil in oil fields or gas from water for gas fields.
b) Three-phase separators, which are used to separate the gas from the liquid phase, and water from oil.

These gravity separators may be either horizontal or vertical pressure vessels with phase separators had an additional of internal components and control devices as shown in the figure 4 below.

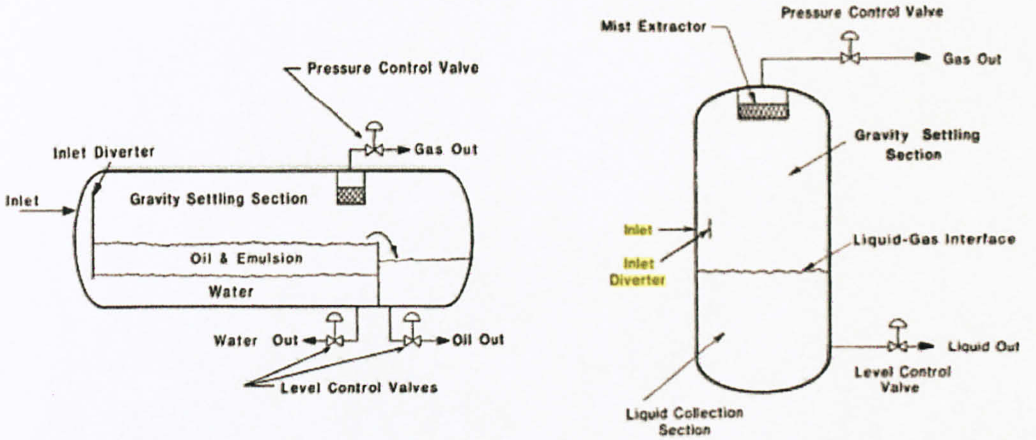

Figure 4: Horizontal and Vertical Separator Schematic. *(Stewart and Arnold, 1999)*

2.3.1 Horizontal Separator

The horizontal separator is more favorable than vertical separator for three phase separation as it has greater interface area to enhance phase equilibrium between oil and water by gravitational settling and provides more surface area for bubbles to escape. *(Stewart and Arnold, 2008)*

Separator Components/Features

The essential features of this separator:

i. Primary separation section (inlet diverter) – for 'bulk' separation of gas from oil.

ii. Secondary separation section – an intersection area above the liquid for gas to separate from liquid by means of gravity.

iii. Mist extractor – to remove small liquid particles from the gas.

iv. Liquid settling section - provide an intersection area for water and oil to settle by gravitational settling and remove gas from liquids.

v. Gas outlet

vi. Oil outlet

vii. Water outlet

(H. Vernon Smith, 1987)

Separation Description

Fluids from well stream enter this separator and hit an inlet diverter affecting changes in momentum. Gross separation occurs when fluids with different density (oil and gas) are separated with gas entering the gravity settling section above the liquid (oil and water) while the liquid sumps to the liquid collecting section at the bottom of separator. Gas flows horizontally and through a mist extractor at the gas outlet. Within the liquid settling section, the oil and water mixture is mixed and rose through the oil and water interface. This promotes the coalescence of water droplets which are entrained in the oil continuous phase. This process is known as water washing where the liquid is ensures to not fall on top of the gas-oil or oil-water interface. The figure below illustrates the principle of water washing. *(Stewart and Arnold, 2008)*

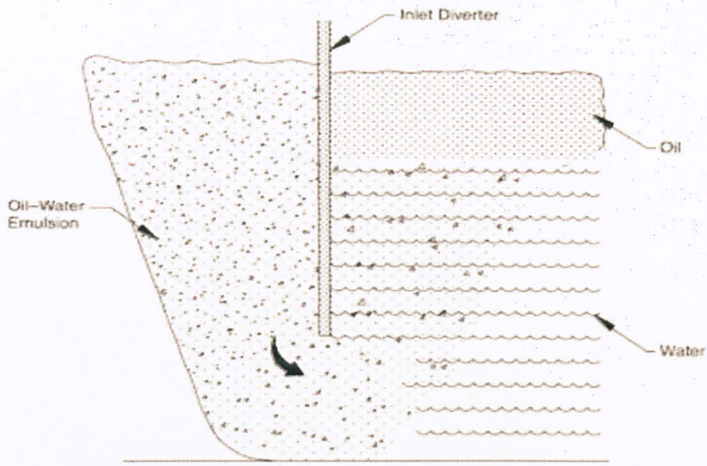

Figure 5: Inlet Diverter Illustrating the Principles of Water Washing.

(Stewart and Arnold, 2008)

In the liquid collecting section, oil and water forms an emulsion at the oil and water interface after had sufficient time to settle by gravitational actions. The free water settles to the bottom of separator.

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2.3.2 Separation Theory

A gravity separator is designed using **Stokes Law** *(George Gabriel Stokes, 1851)* to define the rise velocity of oil droplets based on their density and size. The larger the oil droplet, the faster the rate of rise or rate of separation. The design of the separator is based on the specific gravity difference between the oil and free water. Based on that design criterion, free water will settle to the bottom of the separator while the oil will rise to top of the separator due to their density difference.

(Wikepedia)

Stokes Law

To predict the performance of liquid-liquid separation process, the governed equation used is the Stokes Law.

$$V_t = K\,G\,D^2\,(\rho_1 - \rho_2)\,\mu^{-1}$$

Where

V_t = Rising velocity of an oil droplet

G = Force (gravity for conventional separators)

D = Droplet diameter

ρ_1 = Specific gravity of continuous phase (water)

ρ_2 = Specific gravity of dispersed phase (oil)

μ = Viscosity of continuous phase

K = Constant

Separation efficiency is **directly proportional to drop size** which can be manipulated and must be maintained at all time. Stokes Law indicates that it will take 4 times longer to separate a droplet if it is sheared to 20 microns and 16 times longer if sheared to 10 microns. Separation efficiency is **inversely proportional to continuous phase viscosity which can be lowered by increasing the process temperature.** *(J.C. Ditria et. Al, 1994)*

Oil/Water Settling

A relative motion exists between the droplet and the surrounding continuous phase while separating the oil droplets from water or water droplets from oil. As oil droplet has lower density than water, it tends to move vertically upward under the gravitational force, F_g whereas water as continuous phase exerts a drag force, F_d on the oil droplet in the opposite direction. The oil droplet continues to accelerate until fluid drag force, F_d approaches and balances F_g and will have a constant velocity which known as ***settling*** or ***terminal velocity***. Similarly goes to the motion of water droplets from oil.

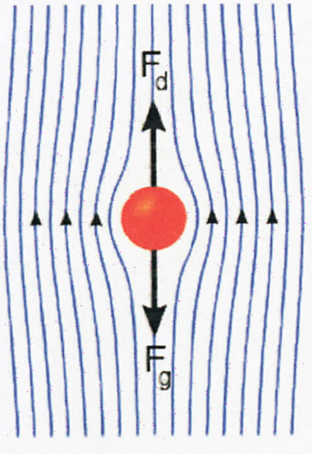


Figure 6: Drag Force, F_d and Gravity Force, F_g Exerted at a Particle. *(Wikepedia)*

From the **Stokes Law**, this droplet settling velocity is inversely proportional to the viscosity of the continuous phase as shown below:

Droplet Settling Velocity, $u = 1.787 \times 10^{-6} \frac{(\Delta\gamma) dm^2}{\mu}$ where $\Delta\gamma = \gamma_w - \gamma_o$

Where

γ_w and γ_o = specific gravity of water and oil

dm = diameter of the droplet

μ = viscosity of the continuous phase

Since oil has greater viscosity than water, the **settling velocity of water droplets in oil is much smaller than the settling velocity of oil droplets in water**.

For the minimum size of droplets that must be removed from continuous phase to achieve a certain oil and water quality at the exit of separator depends largely on the **operating conditions and fluid properties**. *(Abdel Aal et. al, 2003)*

Oil/Water Retention Time

For determining the liquid capacity of two phase separator, only liquid retention time is needed but for three phase separator, the settling of oil droplets from water or vice versa must be considered as well as the retention time constraint. The oil and water retention time which may be different also need to consider. *(Abdel Aal et. al, 2003)*

The oil retention time is defined as a period of time that is sufficient for oil to reach equilibrium and liberates the dissolved gas coalescence and also for free water to coalesce into droplet sizes. Just like oil, water retention time is a certain time for large oil droplets entrained in the water to coalesce and rise to oil-water interface. *(Stewart and Arnold, 1999)*

2.3.3 Separator Performance

The separation of liquid and gas phase performance depends on many factors such as **flow rates, internals, separator operating pressure and temperature, and fluid stream composition and properties**. Changes in any of these parameters may affect the amount of liquid and gas leaving the separator. High velocity of well fluid entering the separator would change the fluid momentum at the inlet and so, more gas is removed from the liquid. **To ensure high liquid capacity of a separator, gas bubbles from liquid must have enough retention time to coalescence**. This can be implied by higher liquid viscosity while considerate on the settling of water droplets from oil. *(Frank Jahn, 1998)* As from field experience, the optimization of oil recovery is done by adjusting separator operating pressure and temperature. **An increase in operating pressure or decrease in operating temperature generally increases the liquid recovered in the separator**. *(Boyun Guo et al, 2006)*

2.4 HYDROCYCLONE INLET DEVICE (HID)

2.4.1 Introduction

An inlet diverter is mounted inside the separator as to reduce the momentum of incoming fluids since when well fluids which have high velocity enter the separator, it hits the inlet diverter and causing a sudden change in fluid momentum. These changes involve fluid flow distribution and thus, affect the gross separation of gas from liquid. Basically, the main concept of an inlet diverter contributes in giving an impact to the inlet stream, changing the momentum and enabling the liquid droplets to fall and the gas bubbles to rise. *(Chin et. al, 2007)*

The various types of internals as instead of open pipe diverter, simple flash plate diverter and such are shown as below in the figure 7:

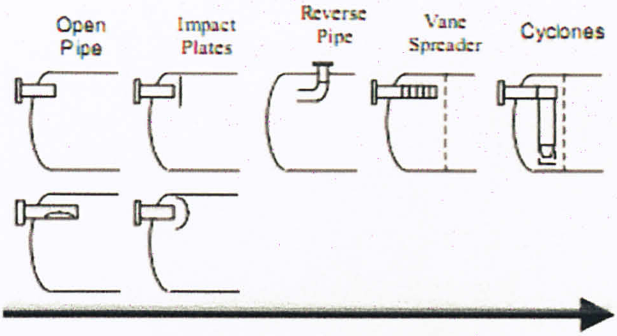


Figure 7: Typical Separator Inlets

From Victor van Asperen et Al at CDS Engineering, he had listed the main functions that should be performed by an inlet diverter as the following:

1. *Reduce the feed stream momentum to ensure good gas and liquid distribution.*
   Any misdistribution of phases that entering into the gas and liquid settling section due to inlet diverter performance may spread a larger retention time and thus, reduce the separation efficiency.
2. *Separate bulk liquids.*
   Good bulk separation will reduce the separation load on the rest of the separator and make the separation operation less sensitive to changes in the feed stream.
3. *De-foam the incoming fluid*
   An inlet device that can breakdown the foam can significantly increase the separation efficiency and reduce the use of chemical. Inlet cyclone is the inlet type that can de-foam better since it applied centrifugal forces and shear to break the foam.
4. *Prevent re-entrainment of already separated liquid and liquid shattering.*
   Re-entrainment can be caused by blowing gas down, or across the surface at too high velocities. This phenomenon usually occurs for vane type inlet device when vessels with half pipes operated at higher gas flow rates than what they were designed for.

2.4.2 Comparison of Inlet Device with their Performance

Table 3: Comparison of Inlet Devices.

Inlet Device Functions	Diverter Plate	Half Pipe	Vane Type Inlet Device	Inlet Cyclone*
1. Reduce the feed stream momentum and ensure good gas and liquid distribution	Good / Poor	Good / Poor	Good	Good
2. Separate bulk liquids	Poor	Average	Good	Good
3. De-foam	Poor	Poor	Average	Good
4. Prevent re-entrainment of already separated liquid and liquid shattering	Average / Poor	Average	Good	Good

(Victor van Asperen et Al, CDS Engineering)

Although an inlet cyclone had good ratings for all inlet device functions, the chosen of an inlet device must be based on the case where it can well-functioning and has the effect to the efficiency of separation.

2.4.3 Hydrocyclone Inlet Device (HID) Work Principle

The inlet cyclones work on the principle of gravity separation by centrifugal accelerating any incoming fluid to high gravity force. The swirling fluids create a high force for separation of gas and liquid. Large foam bubbles are broken due to centrifugal flow. The gas accumulates in the center, forming a gas core, exits through the top of the diverter and flows into the separator gas phase. The liquid drops are slung to the tube wall and removed from gas phase while oil-water coalescence occurs at gravitational settling section of the separator. This is explained that with this cyclonic effect, this device is allowable for high inlet throughput and contributes in initial gas separation. The example of inlet cyclone is shown in the figure 8 below. *(Chin et al, 2007)*

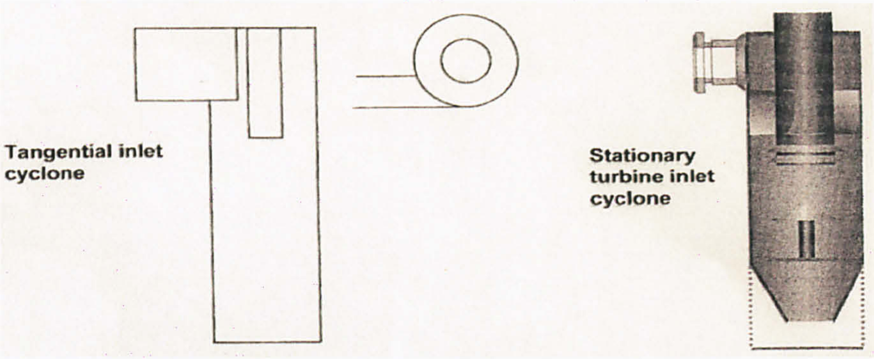


Figure 8: Example of Inlet Cyclones (courtesy of CDS Separation Technologies Inc).

2.4.4 The Separation Problem

Some of the oil and water production from oil/gas continuous wells where water droplets can trap oil droplets or vice versa may cause complex emulsion patterns. Large variations of droplet sizes due to different chokes of wells in water cut production field may add to the complexity of the incoming oil-water mixture. Thus, flexible inlet diverter such as Hydrocyclone Inlet Device (HID) is preferable to provide emulsion breaking as well as separate gas from oil-water emulsion. Complex emulsion may be break with proper applied shear or gravity force level rather than stabilizing the emulsion. **However with cyclone principle performed by HID, more complex oil-water emulsion may occur and encounter difficulty in separating oil and water by means of gravitational settling.** *(Nilsen et. al, 2004)*

2.5 RESERVOIR FLUID AND OIL-WATER MIXTURE PROPERTIES

2.5.1 Reservoir Fluid Components

The reservoir fluid or crude oil is mainly combination of hydrocarbon organic compound such as paraffinic, naphthenic and aromatic and non-hydrocarbon, asphaltic.

Hydrocarbon Components

William D. McCain stated in his book, "The Properties of Petroleum Fluids" that hydrocarbon are organic molecules made up of only carbon and hydrogen.

Alkanes	: one single bond between two carbon atoms
Alkenes	: double bond between two carbon atoms
Alkynes	: triple bond between two carbon atoms

Alkanes compound which has more carbons that saturated with hydrogen atoms is known as **paraffins**. The cycloalkanes which has saturated hydrocarbon rings is known as **naphthenes**. As for **aromatic** compounds, the compounds that resemble benzene chemical behavior where three alternating hydrogen-carbon double bonds within six carbons are arranged in a ring. The **asphaltenes** is large molecules of primarily hydrogen and carbon atoms with 1 to 3 of sulfur, oxygen or nitrogen atoms. These non-hydrogen components will determine the color of crude oil.

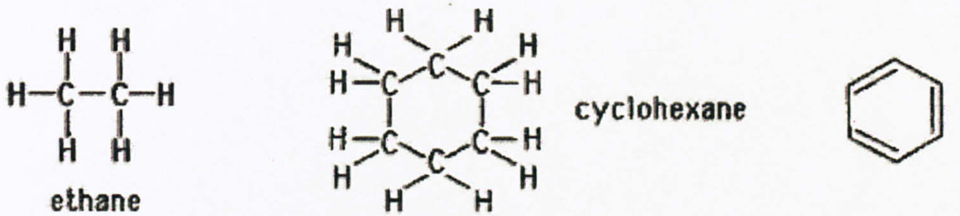


Figure 9: Example of Paraffins Compound: Ethane, Naphthenes Compound: Cyclohexane and Aromatic Compounds: Benzene.

Non-hydrocarbon Components

The non-hydrocarbon compounds in crude oil have significant influence in processing and quality of crude oil although small in volume.

1. Sulfur compounds – able to poison metallic catalyst used in the refining process.
2. Hydrogen Sulfide, H_2S – is poisonous, has bad odour and colorless gas.

3. Mercaptans, RSH where R represents any organic group – more disagreeable odor than H_2S and led to sour crude.
4. Oxygen compounds – able to form organic acids such as carboxylic acid in crude oil causes corrosive products.
5. Nitrogen compounds – nitrogen gas can reduce thermal quality of crude oil.
6. Carbon dioxide – can cause corrosion and give significant impact on fluid properties.

(William D. McCain, 1990)

2.5.2 Reservoir Fluid Properties

Since the crude oil used in this project is obtained from Chendor field, the Chendor Marine Terminal Handbook stated that the aromatic, naphthenic and paraffinic compounds in its crude oil is more than 99% of volume and hydrogen sulfide volume is less than 1%. The characteristic and properties of the crude oil is attached in the appendix at the end of this report.

2.5.3 Oil-Water Mixture Characteristic

The oil-water mixture is prepared as to act as reservoir fluid in this project. However, they can not mix altogether due to the molecular structure behavior and intermolecular forces of oil and water.

Intermolecular Forces

Surface (interfacial) tension is measure of the attractive force acting at a boundary between phases. The attractive force between liquids is known as interfacial tension whereas the attractive force between liquid and gas or liquid and solid is known as surface tension. Interfacial tension determines the ease of separation of oil from water since it determines the size of oil or water droplets depending which phase is dispersed.

The lower the interfacial tension the smaller the droplet of dispersed phase and causes the immiscible mixture to have a single phase (homogeneous mixture). Produced water interfacial tension will be lower with the addition of chemical such as corrosion inhibitors and its attractive force may also change to promote the coalescence of small droplets into larger droplets that separate quickly when demulsifier is added. *(John et. Al)*. In total, the summary of intermolecular forces between molecules is shown as in the following table below:

Table 4: Summary of Intermolecular Forces between Molecules.

Type	Nature of Attraction	Exhibited by
1. Hydrogen bond (H-bond)	The Hydrogen atom bonded to a very electronegative atom can H-bond with electron clouds of a nearby molecule. Usually this if for H attached to either F, O, or N. this is a strong type of interaction.	Molecules with –OH, HF, -NH.
2. Ion-dipole	Electrostatic interaction between one end of dipole and the oppositely charged ion.	Ion and a polar molecule
3. Dipole-Dipole	Electrostatic attraction between dipoles.	Polar molecules
4. Induced dipole – induced dipole (London Dispersion forces)	Attraction occurs because of transient dipoles induced by nearby electron clouds. Generally a weak type of attraction, but becomes strong for every big molecules (because the size of induced dipole is big and spread over a large area of the molecule).	All molecules whether polar or nonpolar. Nonpolar molecules exhibit only this type of attraction.

(Erwin P. Enriquez, 2002)

In water the O-H bond is highly polar due to the large electronegativity difference between the O and H atoms. This H atom bears a large positive partial charge and the O atom bears a large negative partial charge which resulting in strong hydrogen bonding between water molecules. Oil is nonpolar since its only intermolecular force is London Dispersion forces which has the weakest attraction between molecules. The strength increases with increasing size and polarizability of molecules. Thus, oil and water is immiscible since nonpolar compounds tend to dissolve other nonpolar compounds but tend not to dissolve polar compounds due to dissimilar intermolecular attractions for each other. From the figure 11 is shown the example of interaction between dissimilar intermolecular forces for hexane and water. *(Kelley Whitley, ChemProfessor, 2005)*

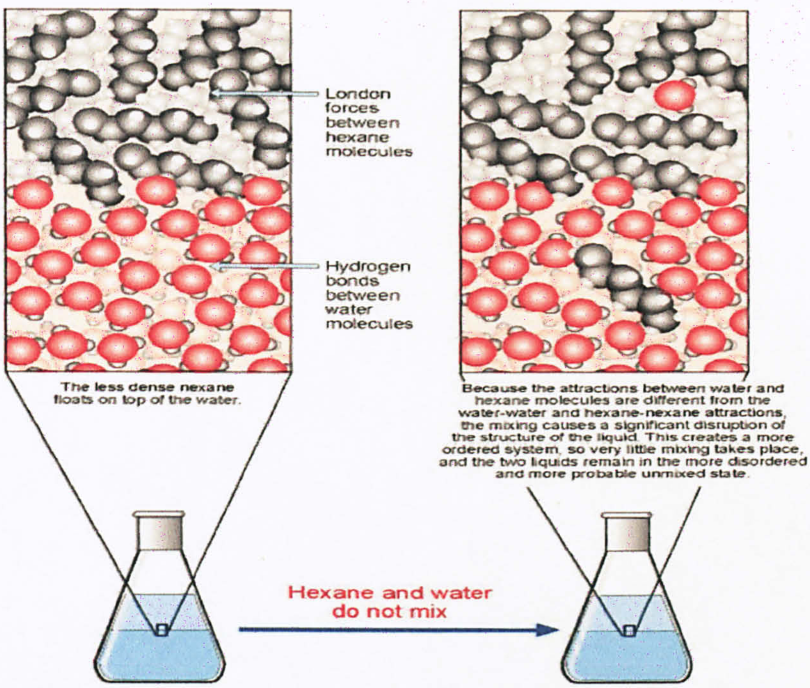
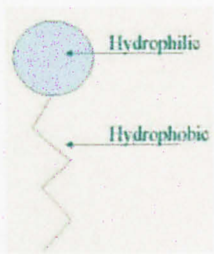


Figure 10: Example of Hexane-Water Mixture.

Hydrophobic-hydrophilic



The hydrocarbon portion is to be hydrophobic (water hating) because it will not hydrogen bond with water but does to tend to dissolve in hydrocarbon liquids. The water-like alcohol and carboxylic acid groups hydrogen bond with water which known as hydrophilic (water loving). If the ratio of the size of the hydrophilic portion to the hydrophobic portion is small, the hydrophilic action is too small to carry the molecule into solution with water. If the ratio is large, it can carry the molecule into solution. Contamination of any surfactants (detergents) will greatly increase water solubility in hydrocarbon.

Surfactant is stand for Surface Active Agent and also referred as wetting agent. Surfactant reduces the surface tension of medium in which it is dissolved. Each surfactant molecule has a hydrophilic (water-loving) head that is attracted to water molecules and a hydrophobic (water-hating) tail that repels water and simultaneously attaches itself to oil. Since oil and water do not mix together but remain as two individual solutions (not as a homogenous mixture), surfactant is introduced to link these two substances and form a homogeneous mixture. One of the surfactants is emulsion agent.

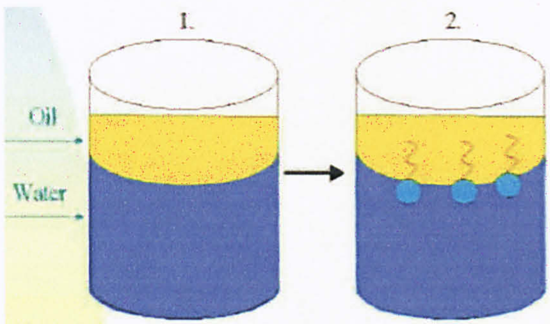


Figure 11: Surfactant in Oil-Water Mixture. *(Princeton Material Institute)*

2.5.4 Fluid Properties

The Ultraspin Pty. Ltd, 2008 website stated that the nature of oil-water mixture has a very large influence on the separation efficiency of all mechanical separators. The most important fluid properties are listed below:

1. Viscosity

   The viscosity of the water falls as the temperature rises. This allows oil droplets to move more easily through the water phase. Thus, increased temperature improves separation efficiency.

2. Droplet Size

   Oil-water separation efficiency of all type of separator will be the highest for larger oil droplets. Very small droplets are more difficult to separate. The nature of the process or application determines the size of oil droplets.

3. Density difference

   The efficiency of separating oil from oil/water mixtures is dependant on the difference in density between the oil and water. The separation efficiency increases as the difference in density increases.

4. Inlet concentration

   For a constant droplet size distribution, increasing inlet oil concentration will not change the separation efficiency but in practice, the droplet size is increases with inlet oil concentration and thus, improves separation efficiency.

2.6 EMULSION

2.6.1 Introduction

Oil and water do not mix but form an immiscible mixture and will form as emulsions if agitated. This mixture would exhibit different fluid properties from pure water or oil properties. The exact definition of emulsion is a colloidal dispersion in which fine drops of liquid is dispersed in another surrounding liquid (continuous phase) of different composition. Three requirements for forming an emulsion;

i. Two immiscible liquids (such as oil and water).
ii. Enough agitation to disperse one liquid into small drops.
iii. An emulsifier to stabilize the dispersed drops.

In oil-water mixture, emulsions are caused by turbulence or agitation due to turbulent flow from the wellbore as the shearing forces break the dispersed liquid into many small droplets. The dispersed liquid is coalesces by interfacial or surface tension between the droplets. Mostly emulsions are not really stable in the oilfield. To form stable emulsion, an emulsifier such as surfactant stabilizes the emulsion by migrating to the oil-water interface and forming interfacial films around the drops. *(Manning and Thompson,1995)*.

Usually the natural emulsifier from the oilfield is the resident in heavy fraction crude which has higher boiling fraction such as asphaltenes and resins, organic acids and bases. *(Sunil L. Kokal, Saudi Aramco)*

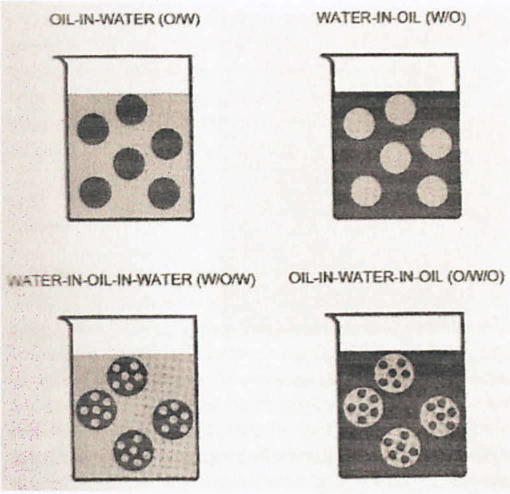


Figure 12: Types of Emulsion.

2.6.2 Types of Emulsion

Two types of emulsion that are already apparent are:

i. Oil-in-water (O/W) for oil droplets dispersed in water.

ii. Water-in-oil (W/O) for water droplets dispersed in oil. *(Schramm, 2005)*

Types of emulsion that is formed based these rules of thumb where component with smaller volume fraction will be dispersed phase and component with larger volume fraction will be continuous phase. *(Sunil L. Kokal, Saudi Aramco).*

In the oilfield, normally water-in-oil (w/o) emulsion is formed rather than the reverse emulsion, oil-in-water (o/w) emulsion. However, in water cut production field, as water cut increases, the possibility of forming o/w emulsion increases. *(Abdel Aal et. Al, 2003)*. Double emulsions or more complex emulsions also may occur depends on the ratio of phase volumes. If the ratio of phase volumes is very large or very small, the phase which having smaller volume is the dispersed phase. As example, oil-in-water-in-oil (o/w/o) containing oil droplets dispersed in aqueous droplets that are also dispersed in a continuous oil phase. *(Manning and Thompson, 1995)*

2.6.3 Emulsion Treatment

Stability of Emulsion

From Abdul Aal et al, 2003, he stated that to separate the emulsion into 2 phases is dependent of the degree of its emulsion stability which is influenced by several factors as following:

i. *Viscosity of oil* : Less viscous oil leads to easy separation.
ii. *Density difference between oil and water phases* : Larger difference is needed for better separation.
iii. *Interfacial tension between 2 phases* : Decreasing the interfacial tension is preferable.
iv. *Size of dispersed water droplets* : Separation is faster as size of water drops is larger.
v. *Percentage of dispersed water* : Small percentage of water in oil under turbulence conditions could lead to highly emulsified mixture.

Breaking the Emulsion

Several ways in breaking the emulsion are by heating, adding chemicals and applying electrical field. However, the most common is by heating since the viscosity of oil reduces with temperature. This results on increment in water droplet settling velocity and subsequently promotes the separation of water from oil. The changes in properties due to high temperature are described more detail in the next section.

Two methods of heating oil emulsions are:

i. Direct heaters : Emulsion is introduced to a heated vessel.

ii. Indirect heaters : Use water as a transfer medium to transfer heat from hot flue gases to the emulsion.

Effect of Temperature

By heating the oil-water mixture, the density or relative specific gravity of both components is reduced. The increase in $\Delta\gamma$ would increase the settling velocity and promotes the separation of water droplets from oil phase. However, the effect is not significant as viscosity since the difference is very small. At high temperature, the difference may be greater but reverse effect on the specific gravity difference also may occur. As example, for heavy oils at a certain temperature, the specific gravity of oil and water will be equal and this must be avoided because it will completely stop the separation. With increased temperature will promote the movement of small droplets and if upon collision with others may form larger size droplets. The increased in droplet size will significantly speed the settling process as mentioned before. **By adding heat to oil-water mixture will help to destabilize the emulsifying film and simultaneously breaking the emulsion.** *(Abdel Aal et. al, 2003)*

CHAPTER 3
METHODOLOGY

3.1 FINAL YEAR PROJECT MILESTONE

For the first semester, the focus of this project is on the feasibility study and research on the principle of oil-water separation and the effect of Hydrocyclone Inlet Device (HID). The research also incorporated with preparation for experiment which includes separator and HID prototype with the list of equipments and materials required. Finally on the second semester, the project is continued by performing experimental setup together with data gathering and analysis.

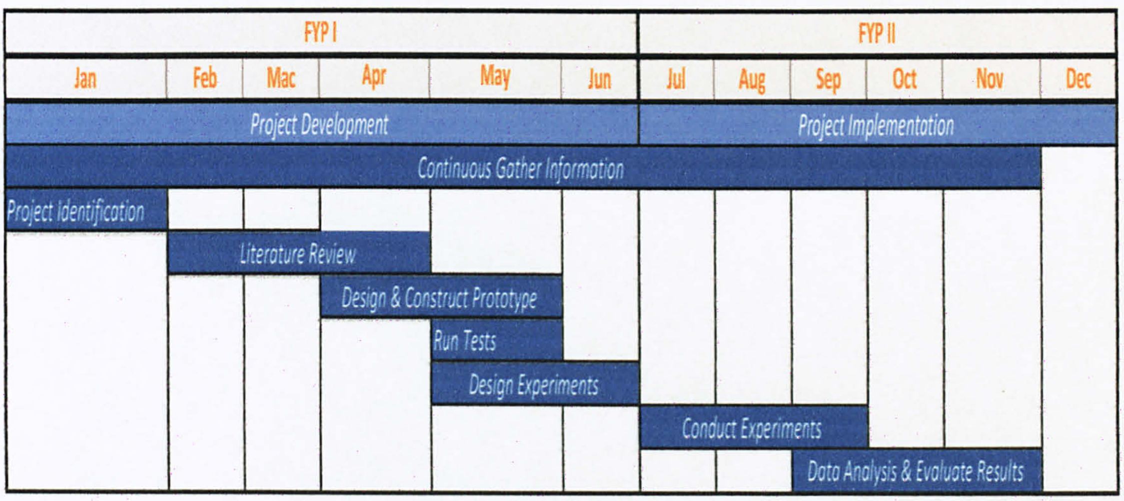


Figure 13: Final Year Project (FYP) Milestone.

3.2 PROJECT PROCEDURES AND STRATEGIES

The figure shown below is the process flow chart of this project in order to achieve its objective.

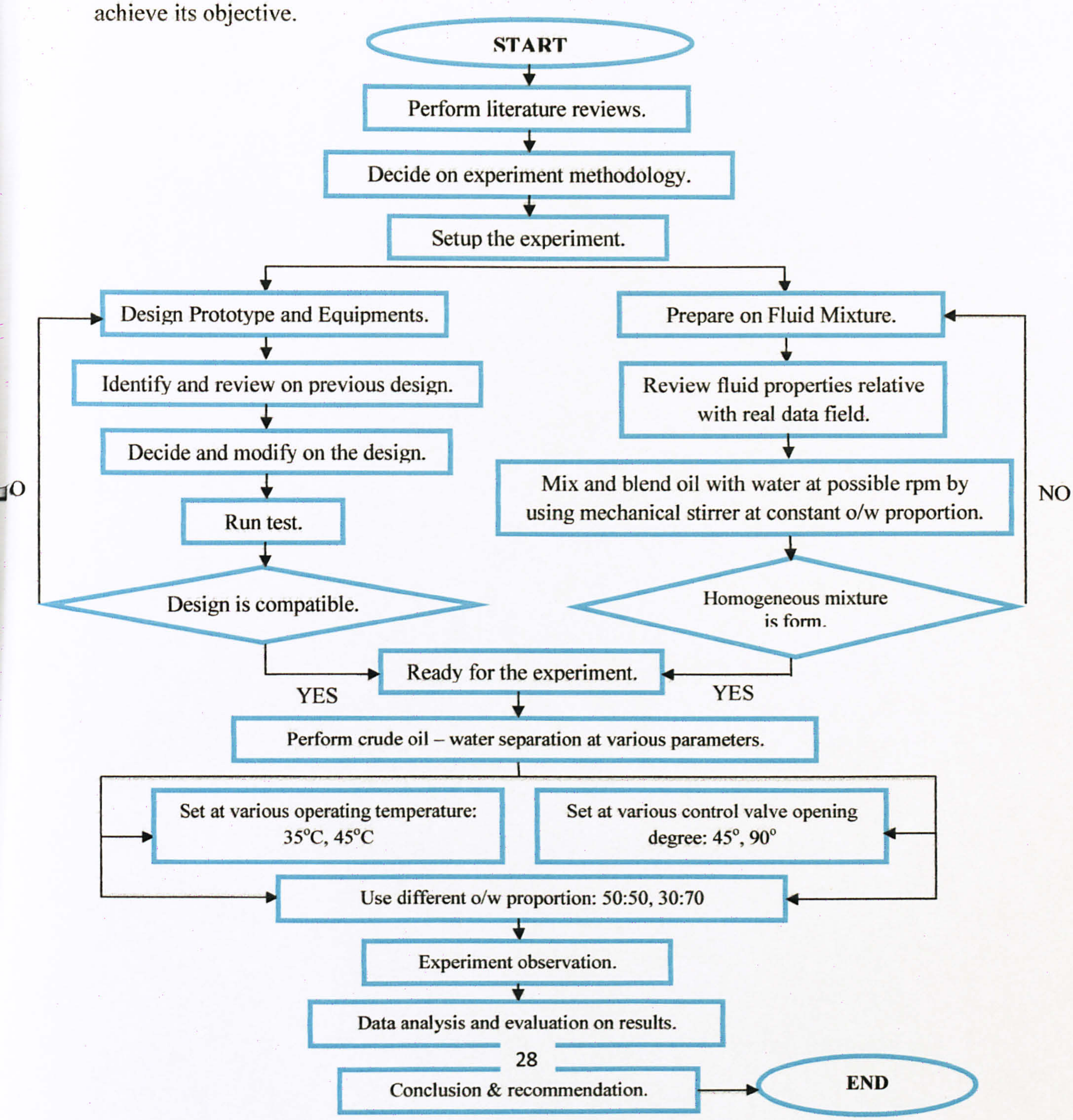


Figure 14: Final Year Project Process Flow Chart.

3.3 REVIEWS ON LITERATURE

The objectives of this project are to reduce oil and water retention time and also emulsion formation as to improve the oil-water separation. From the Literature Review section before, in order to study the effect of Hydrocyclone Inlet Device (HID) in gravity separator, below are the key points which need to include in the experimental approach later.

1. Separator and Hydrocyclone Inlet Device (HID) Prototype
   - Since the main focus is to reduce the oil and water retention time, the effect of HID is observed by measuring the thickness of oil, water and emulsion layer that is formed after the gravity settlement. Thus, the separator design is based on liquid level interface controller.
   - The HID is design using a simple standalone pair of pipe to create centrifugal and swirling action exerted to the incoming fluid into the separator.
2. Fluid mixture properties :
   - Crude oil is used instead of diesel where their properties are different in terms of viscosity and fluid density. The obtained crude is contained of less than 1% of sulfur which is likely to reduce the fluid pH and cause high intermolecular forces between oil and water to form an emulsion.
   - High crude oil and water ratio in the mixture to represent high water cut from production field.
   - Homogeneous mixture of oil and water is prepared by blending continuously using a mixer.
3. Operating parameters :
   - The operating temperature is varies using external heater in order to create different viscosity and increase the density difference of fluids to ease the gravity separation.
   - The flowrate of incoming fluid is varies to create different fluid momentum hitting the HID at the inlet of the separator.

3.4 DESIGN OF SEPARATOR AND HID PROTOTYPE

Since the main focus of the project is to study the effect of HID in oil-water separation by measure the thickness of oil layer which is formed after gravity settlement, a simple design of separator prototype is constructed. The design of the three phase gravity separator is in horizontal orientation using Level Interface Controller design. This basic design allows the oil-water separation process in a gravity separator to be seen and observe clearly from the inlet stream to the gravitational settling section. The dimension of the prototype is based on the real offshore separator vessel which had been scaled down to the ratio of 16. (ratio = 1:16) with capacity of 20L of fluid at a time. Perspex is used as the vessel wall since it is more economical and can resist the oil-water mixture properties at certain temperature and pressure.

Vessel dimension: 1.5 ft x 1ft x 0.47 ft = 0.705 ft^3 = 20 L

This prototype is already used in the previous project and the design of separator prototype is shown in the figure below.

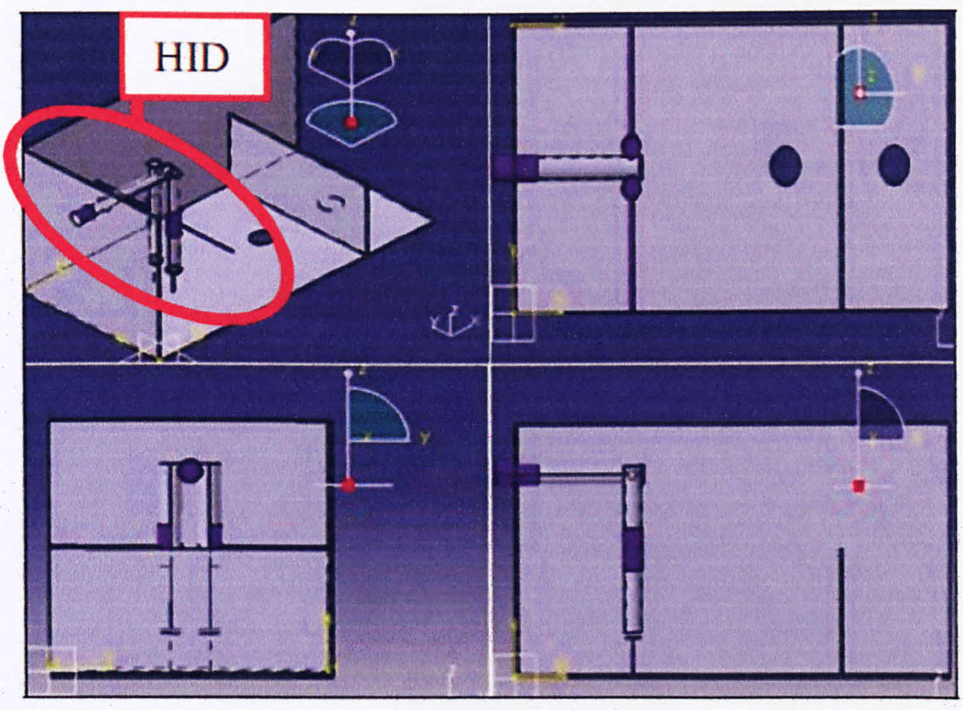


Figure 15: Multi View of Separator Design with Hydrocyclone Inlet Device (HID).

As for Hydrocyclone Inlet Device (HID), a pair of PVC tubes is designed with simple basic design of cyclone as advised by Mr. Nazarudin, Angsi Field Engineer of Peninsular Malaysia Operation (PMO), PETRONAS Carigali Sdn. Bhd., Kerteh. It is a long and straight cylindrical tube without any additional component inside the tube. This HID is used to create centrifugal and cyclonic action exerted towards the incoming fluid which resulting in the momentum changes of the fluids and subsequently allow the bulk separation between oil and water to occur. This HID prototype is mounted at the inlet diverter of the separator prototype as shown in the figure above.

3.5 ANALYSIS ON REAL DATA

In order to get more information on the performance of mature fields which have higher water cut percentages, research are done with analysis data from selected field of Peninsular Malaysia Operation (PMO) of PETRONAS Carigali Sdn. Bhd. (PCSB), Kerteh. At Peninsular Malaysia Operation, there are several fields which encounter high water cut percentages. These fields are known as mature or brown fields instead of green fields for fields that yield high oil and gas production. The amount of water which is produced together with hydrocarbon fluids is kept increasing since the hydrocarbon fluids reserve had been declined and more water breakthrough into the wellbore. So as to obtain the percentage of produced oil and water from the wells, the well data is captured by the well fluid sample taken at the test separator.

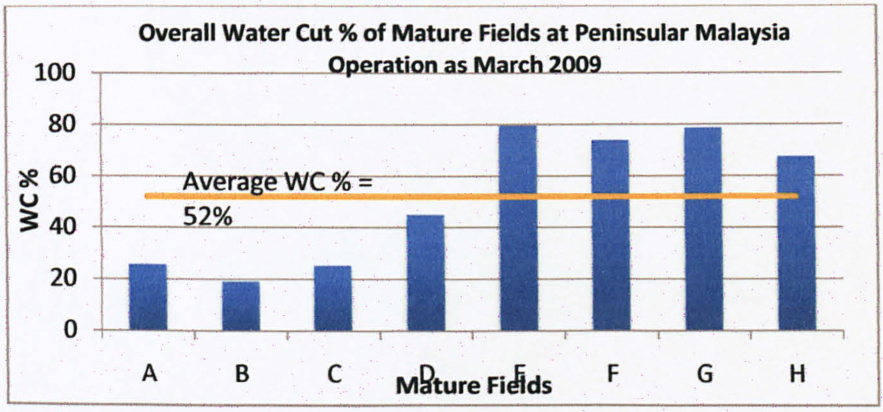


Figure 16: Overall water cut % of mature fields at Peninsular Malaysia Operation as March 2009.

From 89 production wells in this selected mature field, there are some wells which produce greater than 50% of water cut percentages and as overall, the current state of mature fields at Malay basin is in general at 52% of water cut as shown in the figure 18 above. With varying amount of water production from wellheads in each field, the separation of water from oil may be more difficult. Since these mature fields experienced a quite high water production, implementation of Hydrocyclone Inlet Device (HID) in the production separator at surface production facilities may enhance the oil recovery and more economical rather than rejuvenate new equipment.

3.6 OIL-WATER MIXTURE PREPARATION

Oil and water is immiscible if mixed together due to their different intermolecular forces and exhibit two phases. They may have 3 phases if the mixture is agitated together with emulsion agent to create another emulsion phase. In the real mature reservoir, the actual reservoir fluid is actually contained of brine despite of water. Since from the definition the brine is saturated water that contained of 1000ppm of salt in water, the brine is prepared by adding 10g of Sodium Chloride, NaCl in the 10L of water. This 10L brine is used in the preparation of 50:50 of oil and water proportion for a total volume of 20L of oil-water mixture. For the 30:70 of oil and water proportion, the oil-water ratio is changed to 6:14 for 20L of oil-water mixture. Therefore, another 4g of Sodium Chloride is added into 4L of water in order to have a total of 14L of brine while 4L of oil is discharged out from 10L of oil volume. However, through out the report, the name of oil-water mixture is used regardless of oil-brine mixture to indicate clearly the purpose of this project is to measure the separation between oil and water.

In order to observe and measure effectively the layers of phases that are created after the gravitational settling for a certain retention time, the oil-water mixture which resemble to reservoir fluid must be well mixed since the effective of HID will be observed by the height measurement of oil, water and emulsion layers that are formed after the gravitational settling. Hence, several actions are taken to ensure a homogeneous mixture is formed such as varying rpm of stirrer and fluid temperature.

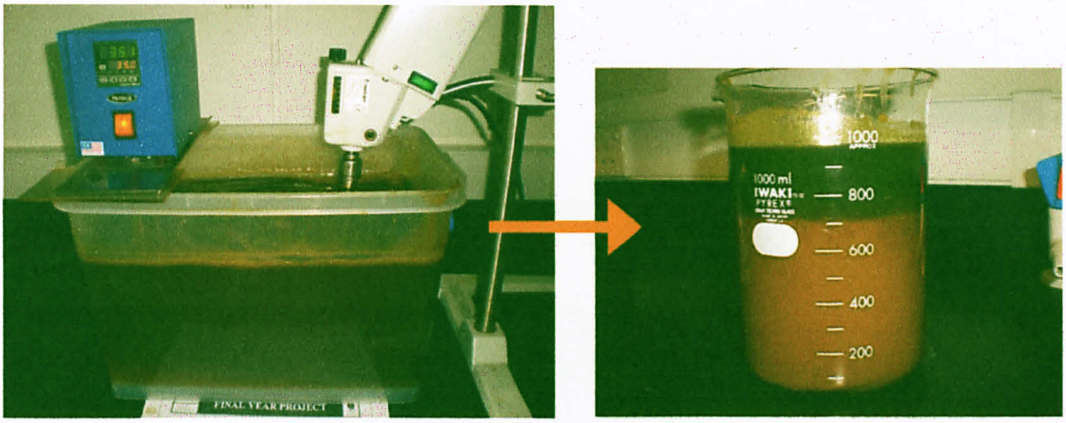


Figure 17: The Final Oil-Water Mixture.

However, it is impossible to mix the oil and water totally into a homogeneous mixture unless highest rpm of stirrer is used which at high turbulence, the smaller the water droplets and more stable the emulsion will be formed. Due to the limitation of the equipment, it is assumed that the reservoir fluid has not much turbulence or agitation exerted to it since the stability of emulsion dependent on the type and severity of agitation applied to it. Thus, for this case, the prepared fluid mixture is contained of unstable emulsion which should be more easily to separate later as shown in the above figure.

3.7 EXPERIMENTAL SETUP

By using waste crude oil and water as hydrocarbon reservoir fluid, the process flow of the experiment is shown as below.

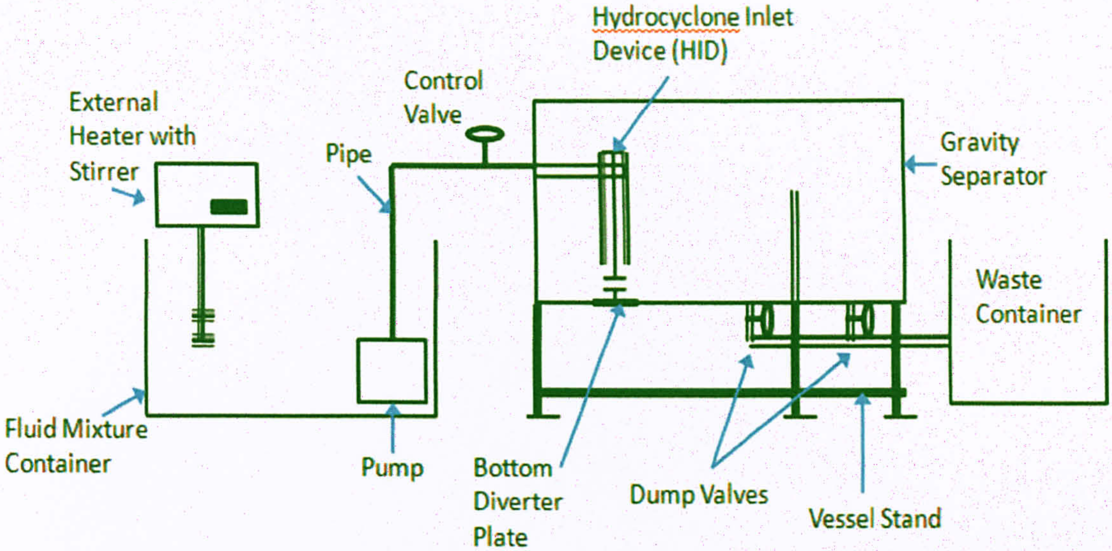


Figure 18: Experimental Layout of Gravity Separator with HID.

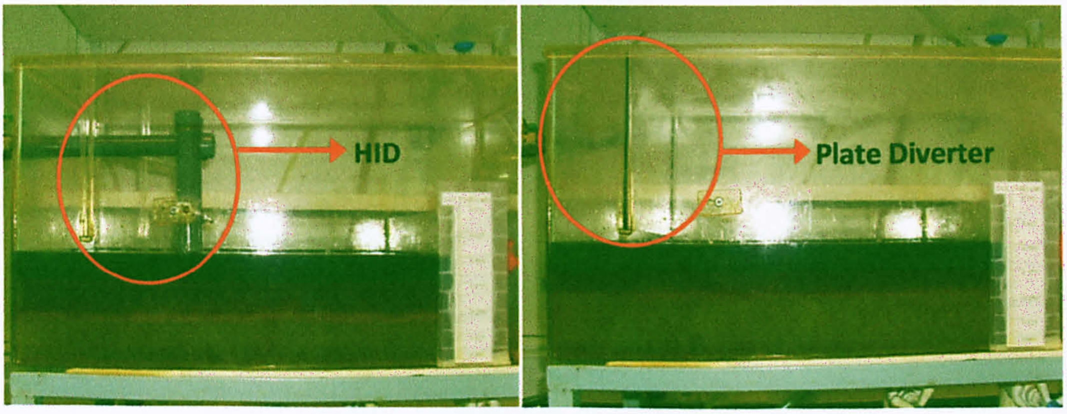


Figure 19: Separator retrofitted with HID and Plate Diverter.

Mix 20 liter of oil-water in the mixture container for 5 minutes to ensure oil and water are mixed together.

↓

Set the temperature of external heater at 35°C.

↓

Let the control valve open with 45° opening.

↓

Switch on the pump and let the oil-water mixture fill in 15L of the separator.

↓

Measure the oil, water and emulsion thickness for every minute until oil and water is settle and reach its phase equilibrium to its phas e respectively.

↓

Record the measurement up to 20 minutes.

↓

Dump the fluid mixture through the dump vessel outlet at the bottom of separator.

↓

Repeat the above steps with 90° of valve opening and at another temperature of 45°C.

↓

Replace HID with plate diverter and repeat the experiment at optimum condition.

↓

Prepare another mixture of oil and water with 30:70 ratio and repeat the experiment.

Figure 20: Experimental Procedure.

The effectiveness of the separation will be measured by the thickness of the oil and emulsion pad and time taken for the oil droplets to coalescence into larger droplets at the oil-water interface.

3.8 TOOLS/EQUIPMENTS REQUIRED

Tentatively, the main component required to construct the experiment is shown in the table below:

Table 5: List of Tools/Equipments Required.

No	Items	Function
Chemical Substances		
1	Waste Crude Oil	Act as hydrocarbon fluid from reservoir which needs to separate.
2	Water	Mix with hydrocarbon fluid.
3	Sodium Chloride	Act as brine which contain of 1000ppm of salt in 1 liter of water
Mechanical Equipments		
1	PVC tube	Act as Hydrocyclone Inlet Device in the separator.
2	Perspex	Act as vessel/separator wall and plate diverter.
3	Submersible Pump	To pump oil-water mixture to the separator.
4	Container	To fill in with oil-water mixture and waste fluids mixture.
5	Mechanical Stirrer	To mix/prepare an oil-water mixture.
6	External Heater	To supply heat to the fluid mixture.
7	Power Supply	To provide power for the stirrer and pump.
8	Tube Pipe	To allow the outflow of fluid from the separator.
9	Globe Valve	To control the fluid flowrate by adjusting its degree of opening.
10	Level Indicator	To measure the thickness of the layers that is formed after gravity settling separation.
11	Hand Glove	To handle crude oil properly and for safety purpose.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 EFFECT OF HID AT DIFFERENT FLOWRATE

Oil-Water proportion = 50:50 = 10:10 of 20L oil-water mixture

Temperature = 35°C

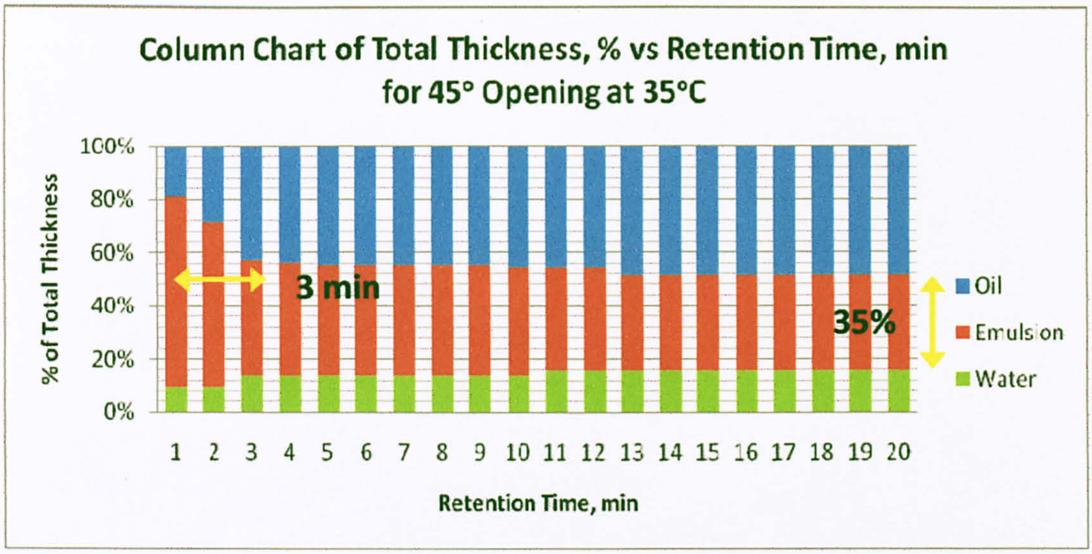


Figure 21: Column Chart of Total Thickness vs Retention Time for 45° Opening.

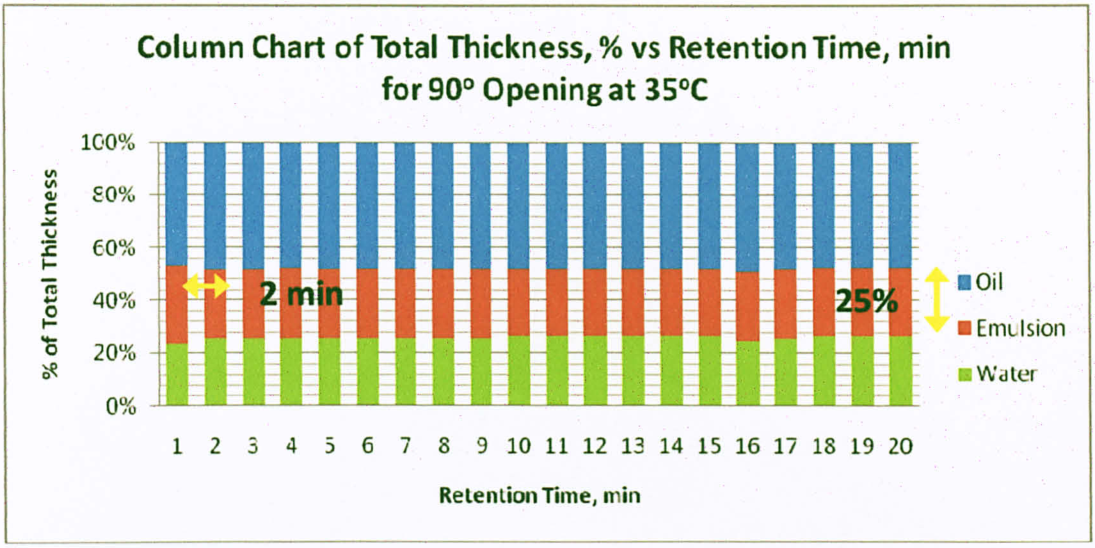


Figure 22: Column Chart of Total Thickness vs Retention Time for 90° Opening.

4.1.1 Oil-Emulsion-Water Thickness

From the figure 21 and 22 the above, the thickness of layers for oil, water and emulsion that is formed are differed with each other. At 45° opening, about 35% of the total height of separator in average is covered by the emulsion which is 10% higher than the emulsion thickness at 90° opening. By operating HID at 90° opening (higher flow rate) also allowed the emulsion to break into oil and water phases which resulting in more oil and water thickness. This is shown that at high flow rate, the changes in momentum of fluid hitting the HID eased the separation of oil and water at the inlet of the separator. This high velocity swirling flow creates a radial acceleration field from HID allowed the gross separation between fluids with different densities which is in this case is oil and water. Due to this fluid behavior, the cyclonic effect provided by HID is concluded to function better at high fluid flow rate.

4.1.2 Retention Time

At high flow rate, the oil retention time as shown in the figure 22 only took less than 2 minutes which is 1 minute lower for 45° opening in the figure 21. This is shown that after the centrifugal force provided by HID, the oil droplets need less time to coalescence with larger oil since the gross separation at the inlet had happened before allowed the oil to arise fast to the oil-emulsion interface. This provided that high fluid flow rate contributed in separating oil from water phase in less time with the aid by work done from HID.

4.2 EFFECT OF HID AT DIFFERENT TEMPERATURE

Oil-Water proportion = 50:50 = 10:10 of 20L oil-water mixture

Fluid Flow rate = 6.5L/min (optimum 90° valve opening)

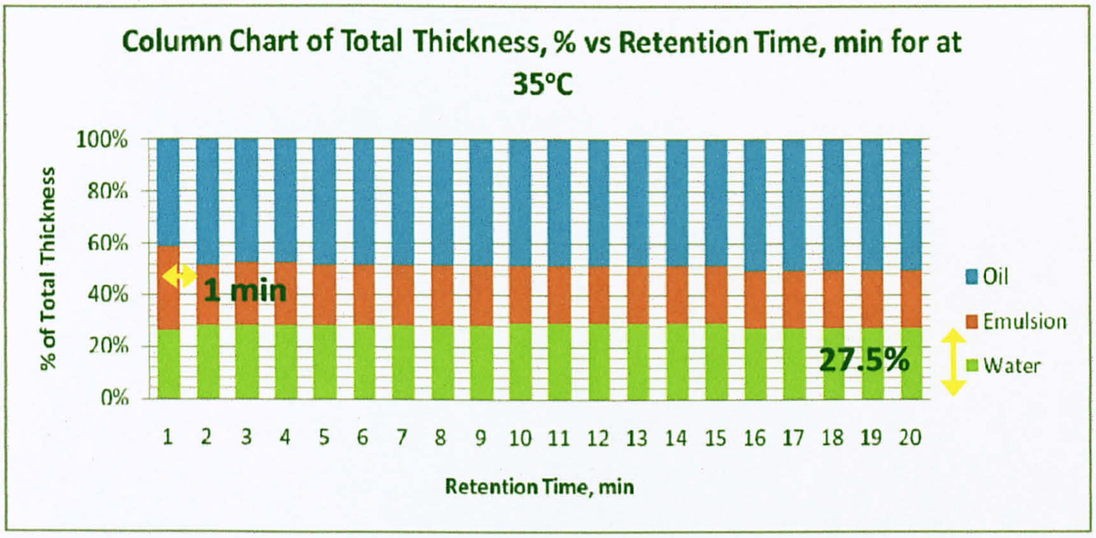


Figure 23: Column Chart of Total Thickness vs Retention Time at 35°C.

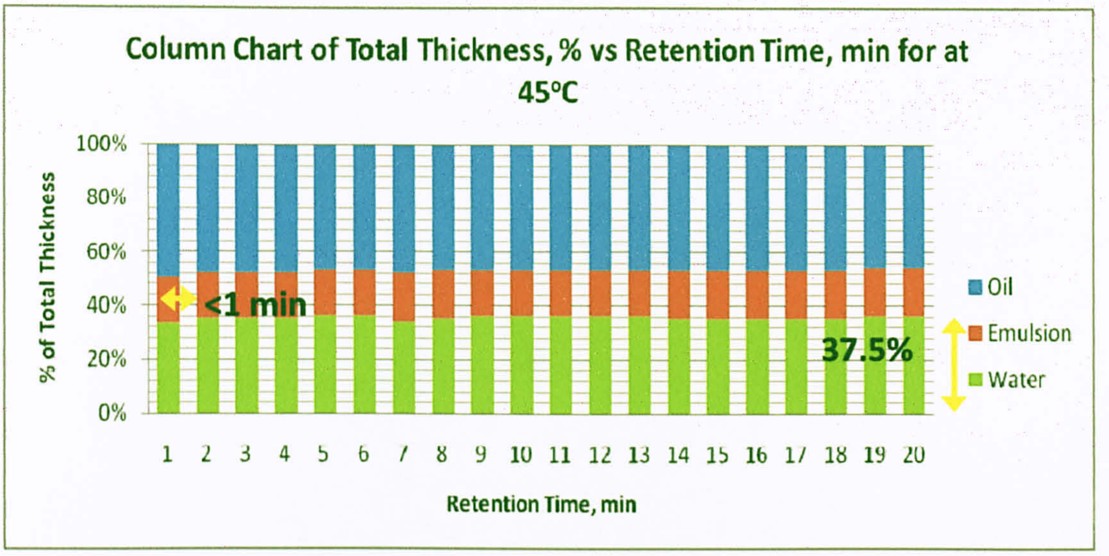


Figure 24: Column Chart of Total Thickness vs Retention Time at 45^{0}C

4.2.1 Oil-Emulsion-Water Thickness

From both figure 23 and 24 as shown in the above, the total of oil recovery and amount of emulsion formed at both temperature is almost the same. However, at high temperature of 45°C, the thickness of water that is formed after the gravity settling is 10% higher than the water thickness at 35°C. By supplying heat to the fluid, the intermolecular forces between oil-water molecules in emulsion had been reduced which means that the attraction between both molecules becomes weaker. Since water is less viscous than oil, water droplets can release the attraction with oil droplets easily with the swirling aid from HID and resulted more water is separated from the emulsion. Here with this justification, the HID is preferable to operate at high temperature.

4.2.2 Retention Time

At 35°C, oil droplets take about 1 minute to start to coalescence whereas less than 1 minute required at temperature of 45°C as shown in the figure 23 and 24 respectively. Oil droplets movement at low temperature is very much slower than at 45°C to reach its phase equilibrium. This is due to the mixture properties which had stated that, at high temperature, viscosity of continuous phase will be reduced. Thus by following the Stokes Law,

$$V_t = K\,G\,D^2\,(\rho_1 - \rho_2)\,\mu^{-1}$$

as the viscosity of continuous phase (water) is reduced, the rising or terminal velocity of oil droplets will be more faster and rapid and resulting in earlier separation. With the HID acting on the incoming fluid mixture at this condition, it provided better results in reducing water retention time compared at low temperature.

4.3 EFFECT OF HID AT DIFFERENT OIL-WATER PROPORTION

For this case, the experiment is done at the optimum condition with the following parameters shown below:

Temperature = 45oC

Flow rate = 6.5L/min (optimum 90° opening)

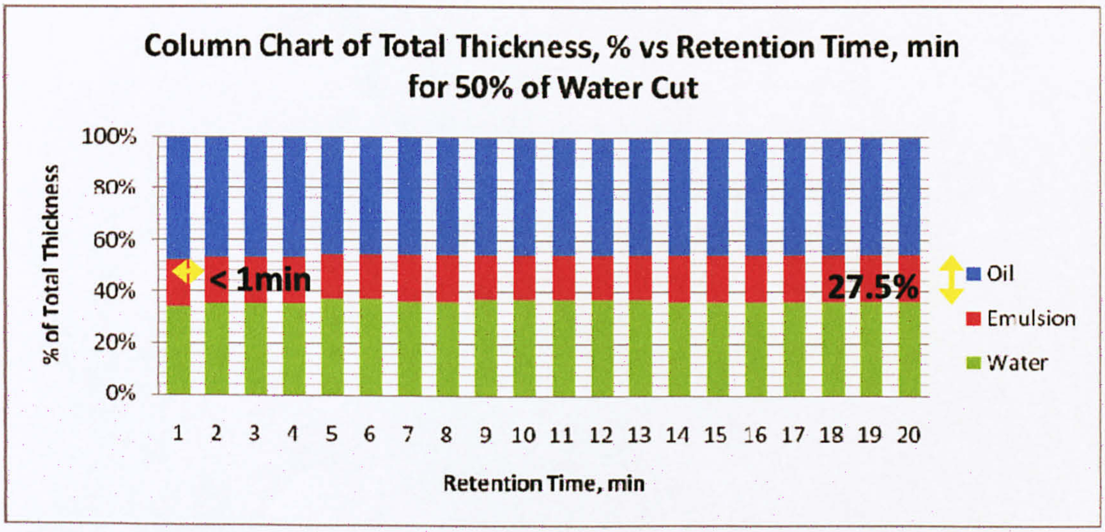


Figure 25: Column Chart of Total Thickness vs Retention Time for 50% Water Cut.

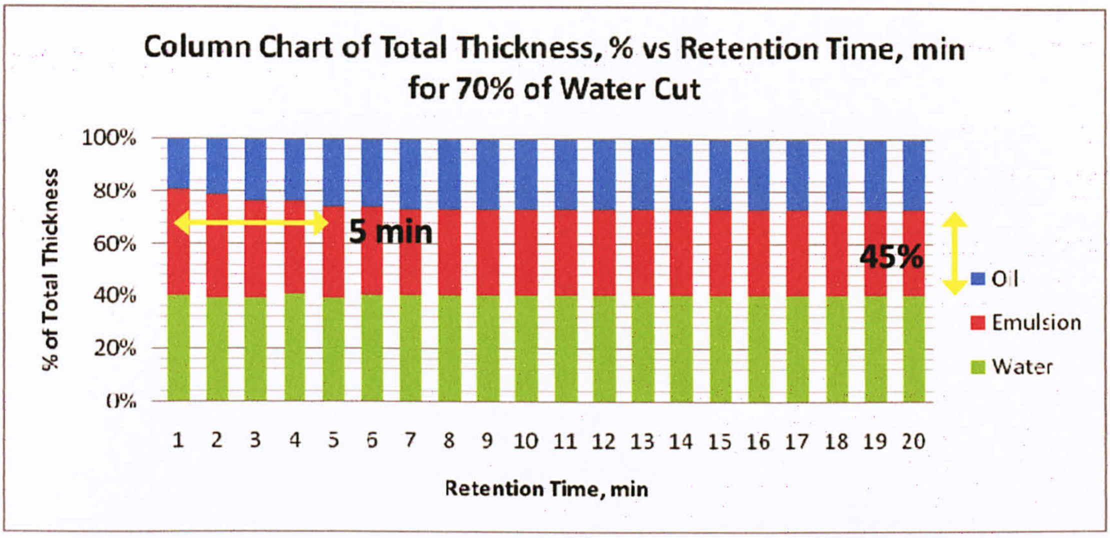


Figure 26: Column Chart of Total Thickness vs Retention Time for 70% Water Cut.

4.3.1 Oil-Emulsion-Water Thickness

At 50% of water cut, the amount of water separated from the oil is almost the same with the amount of water at 70% water cut. Conversely, more oil is recovered in the figure 25 with 45% of the total thickness is covered by the oil compared to 27.5% of water thickness in the figure 26. From both of the results obtained, it is unexpectedly that at high water cut, the effectiveness of HID in separating the oil and water is reduced. More emulsion is formed at 70% of water cut for about 15% from the thickness of emulsion at 50% of water cut. This result shown that HID can not functioning well at higher water cut. The justification on this phenomenon can be explained by the type of emulsion that is formed. For 50% water cut, the emulsion that is formed could be water-in-oil emulsion which is normal for every existing well. However, at higher water cut, from the rules of thumb for emulsion formation, more water as continuous phase can cause reverse emulsion, oil-in-water emulsion to be formed. By having this type of emulsion, the swirling action by HID may cause more complex oil-in-water emulsion due to the high ratio of water-oil phase volume and different sizes of oil and water droplets that are formed.

4.3.2 Retention Time

In terms of retention time, the oil droplets required more time to coalescence and settle by 4 minutes lower at higher water cut compared to 50% of water cut as shown in the figure 25 and 26 above. Since design of separator is usually dependent on the oil retention time, having water as the continuous phase due to high water-oil ratio caused the designation of separator is based on the oil droplets. As the water layer is thicker than the oil layer, the oil droplets need to travel more than usual from water continuous phase resulting longer time to coalescence with larger oil droplets is required. Thus, at high water cut, the acceleration on centrifugal force provided by the HID did not really assist the separation of oil and water.

4.4 EFFECT OF HID AND PLATE DIVERTER AT DIFFERENT OIL-WATER PROPORTION

For this set of experiment in the objective is to observe the effect of different inlet device in separating oil and water at different water proportion. The experiment is conducted at optimal condition as below:

Temperature = 45^{o}C

Flow rate = 6.5L/min (optimum 90^{o} opening)

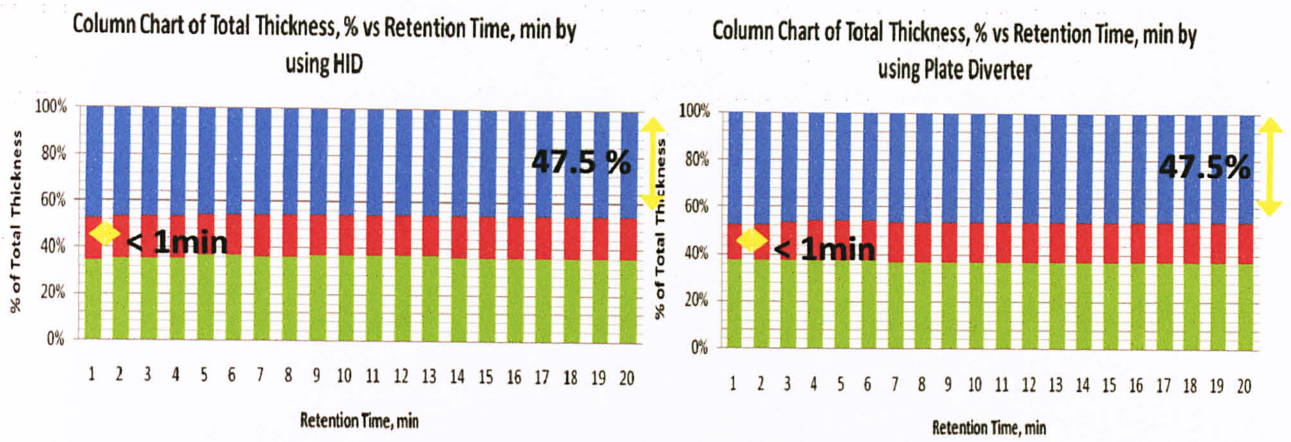


Figure 27: Column Chart of Total Thickness vs Retention Time by using HID and Plate Diverter at 50% Water Cut.

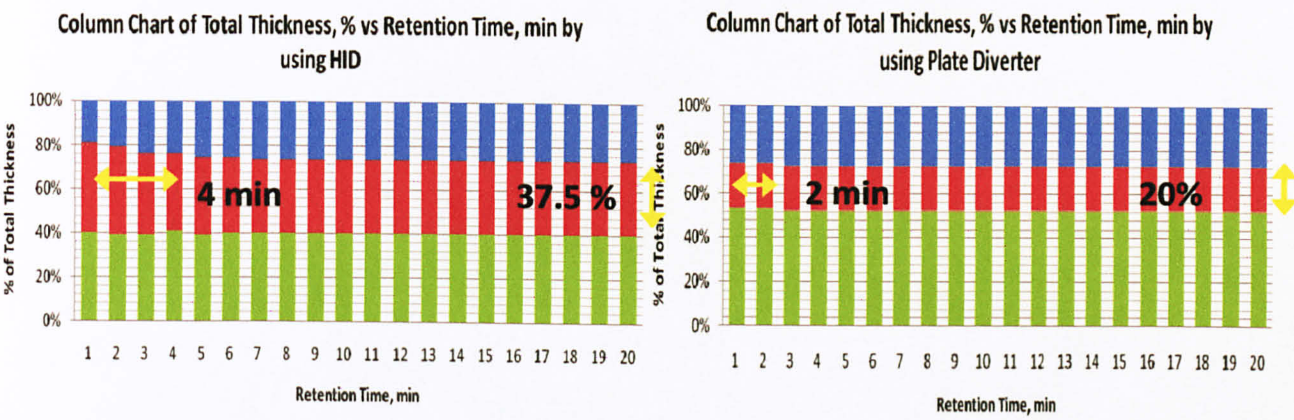


Figure 28: Column Chart of Total Thickness vs Retention Time by using HID and Plate Diverter at 70% Water Cut.

4.4.1 At 50% of Water Cut

From figure 29, it is shown that separator while using HID and Plate diverter in its inlet had caused almost the same effect on the thickness of oil, emulsion and water layers after gravitational settling. At 50% of water cut, both diverters can function properly and recover amount of oil at around of 47.5%. The time taken for oil droplets to coalescence and move to the oil-emulsion interface had required less than 2 min for both diverters.

Although HID used the advantage of centrifugal force and gravity force to separate the oil and water compared to plate diverter, the results is not much difference without having HID as the inlet diverter. This is shown that the both diverters have equal performance at 50% of water cut.

4.4.2 At 70% of Water Cut

Meanwhile at 70% of water cut, the plate diverter work efficiently compared to HID. This is shown in the figure 28 where plate diverter reduced the emulsion layer to 17.5 % compared to oil-water separation performed by HID. In terms of retention time, HID is also lacking behind with 2 minutes more is required to settle down the oil droplets from water continuous phase. The advantage in accelerating the centrifugal and gravity forced acting by HID is dependent on the ratio of oil-water phase volume. With high water-oil ratio, HID can cause complex emulsion despite of break the emulsion. Conversely with simple work principle acting by plate diverter, the plate is hit by incoming fluid and caused the changing in fluid momentum to ease the separation between oil and water. While for HID which cause some turbulence by its swirling action caused more stable emulsion and complex emulsion to be formed.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

From the obtained results before, the effect of Hydrocyclone Inlet Device (HID) at different operating parameters shown that HID performed better at high temperature and flow rate. This due to changes in the fluid behavior where high temperature caused reduction in fluid viscosity to allow more rapid settling velocity of droplets to be occurred as stated in the Stokes Law. Meanwhile, at high flow rate, fluid with high momentum hitting HID and caused high swirling action by HID to ease the gross separation between fluid with different densities which are oil and water. However, the HID can not performed well at high water-oil volume ratio, since there is formation of stable reverse emulsion and complex emulsion due to high turbulence of swirling action performed by HID. The simple design of HID might be one of the effect that affecting the performance of HID. Since there is time frame limitation for this project, the new design of HID will be recommended in the next section.

As conclusion, from all the observation and data obtained, it is concluded that HID has low efficiency in separating oil and water at high water cut compared to plate diverter of gravity separator which is commonly used in the oil surface facilities nowadays.

5.2 RECOMMENDATIONS

Throughout the project, there are some limitation that become constraints to the project which affecting the results in studying the effect of HID at several parameters. Among of them are:

1. Material used

   The material used in the experiment is waste crude oil. Since waste crude oil is contained of some hazardous material such as mercury and hydrogen sulfide, a proper handling and housekeeping after the experiment is required to avoid any misconduct that lead to any unexpected accidents.
2. Effectiveness of HID

   The effectiveness of HID is dependent on amount of oil recovered. Since the current design of HID is based on the simple design of tube, there is need some modification on it.
3. Equipment limitation

   Although the fluid mixture is prepared at 20L volume, only 15L of the fluid had successfully filled in into the separator. This is due to the type of pump used which is a submersible pump. Other than that, at high temperature, the tube of the pump attempted to loose and caused outflow of the incoming fluid and reduced the fluid momentum at the inlet of separator. At small degree of opening valve, the pump function is affected and reduced the fluid flow rate.
4. Commercial of HID

   For the current oil and gas economic nowadays, the proposal to use HID at the gravity separator is not really confirmed since no economic evaluation is done.

Therefore, some recommendations to solve all the above problems are listed as followed:

1. Proper material handling and workspace

   Since the material is hazardous, proper protective equipment such as hand glove, lab coat, goggle and etc is required to handle the waste crude while performing and housekeeping of the experiment. The workstation with adequate place for conducting the experiment is also required.

2. Design of HID

   The design of HID with addition of some component such as vortex breaker and swirling blade and also the additional of cyclone tubes in series may assist in better result to ease the separation of oil and water.

3. Selection of equipment

   Use centrifugal pump instead of submersible pump since it is made by high resistance material and allocated at the outside of the fluid container which will not affect the volume of fluid to be pumped into separator.

4. Economic evaluation analysis

   The evaluation on the economic analysis on the HID compared with other type of inlet diverter may result in a comprehensive research and more convenient in commercializing the application of HID at the inlet of a gravity separator.

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APPENDIX

Appendix I: Sample of Well Test Data. (courtesy from PMO Production Planning)

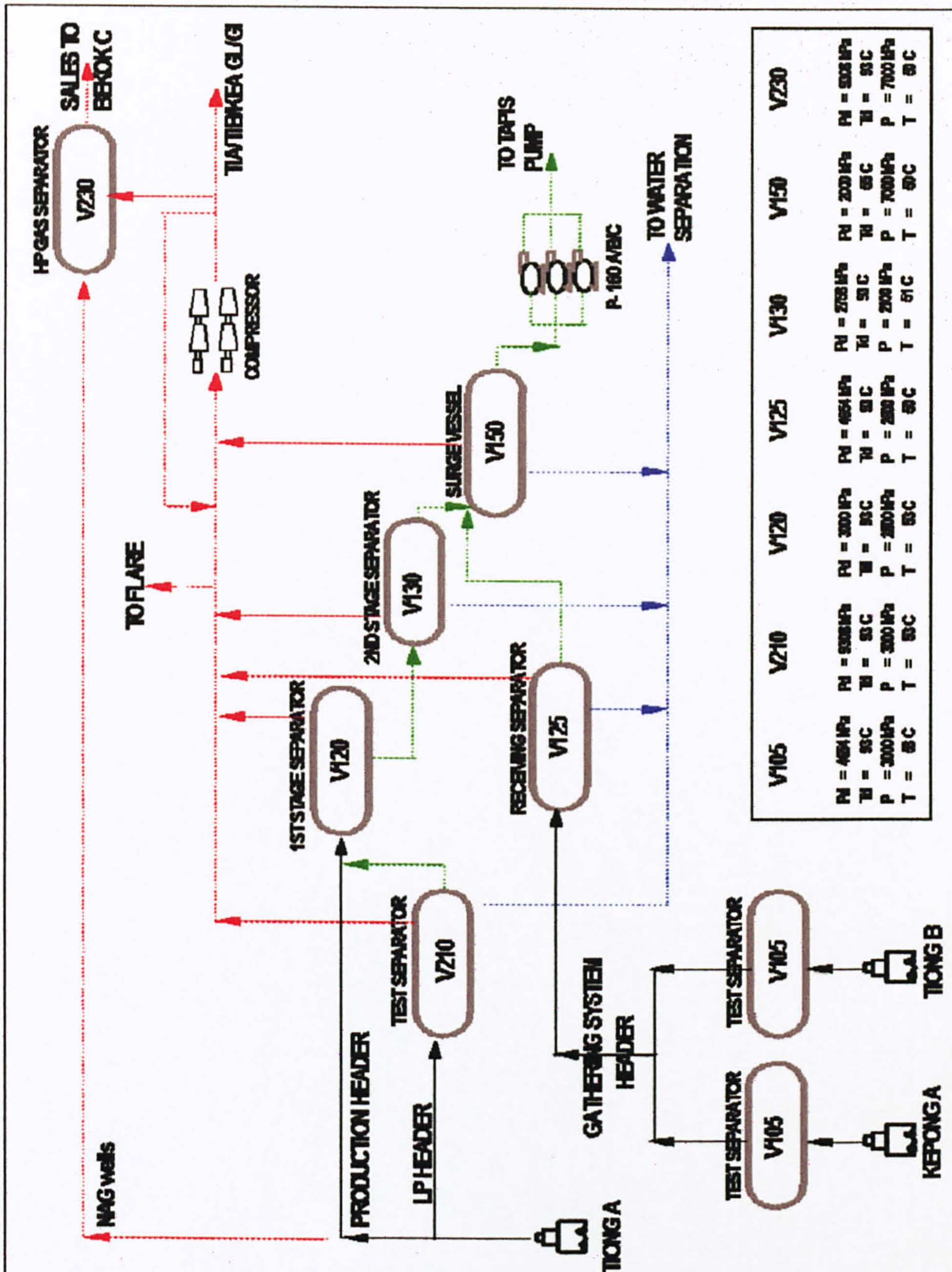
MARCH 2009 WELL TEST COMPLIANCE

BEKOK A

As of 23 March 2009

#	WELL	SERVICE TYPE	TEST #	TEST DATE	DURATION (HRS)	CHK (%)	THP	TEST OIL KL/D	TEST OIL STKL/D	TEST WTR KL/D	TEST GAS KM3/D	GL GAS KM3/D	AUTO CALCULATED GOR Mcf/bbl	AUTO CALCULATED GAS RATE MMcf/d	AUTO CALCULATED WC %	AUTO CALCULATED WATER bwpd	GL CHK (%)	GL SYS PRESS (KPAG)	CASING PRESS (KPAG)	S/OUT BSW (%)	STATUS	
1	A-01	OIL	1	08-Jan-07	6	32/64	9800	72.2	59.9	14.4	125.6	0	9.76	4.43	16.6	91	nil	0	10200	20	OK	Drop in gas produced. To be monitor next month.
	Zone K-25		1	03-Feb-07	6	32/64	9400	73.1	60.7	0.0	122.2	0	9.38	4.32	0.0	0	nil	0	11000	0	REJECT	
			2	03-Feb-07	6	32/64	9400	64.1	53.2	9.6	122.7	0	10.74	4.33	13.1	61	nil	0	11000	20	OK	
			3	23-Feb-07	6	20/64	10000	57.1	47.4	0.0	92.7	0	9.11	3.27	0.0	0	nil	0	11500	0	OK	
			1	04-Mar-07	6	20/64	9800	60.0	49.8	15.0	98.9	0	9.25	3.49	20.0	94	nil	0	11400	20	RETEST	To confirm on water production
			2	17-Mar-07	6	20/64	10000	36.6	30.4	9.2	75.1	0	11.51	2.65	20.0	58	nil	0	11700	20	OK	Confirmed choke size had impact on production. Test to confirm.
			1	05-Apr-07	6	20/64	9800	38.3	31.8	9.6	83.0	0	12.15	2.93	20.0	60	nil	0	11300	20	OK	
			1	03-May-07	6	20/64	9700	41.2	34.2	10.3	84.5	0	11.51	2.98	20.0	65	nil	0	11400	20	OK	
			1	22-Jun-07	6	20/64	9600	50.3	41.7	12.4	94.7	0	10.57	3.34	19.8	78	nil	0	11400	20	OK	Test after 5 days total shut down. Need to monitor next month.
			1	02-Jul-07	6	20/64	9500	52.8	43.8	13.2	100.8	0	10.72	3.56	20.0	83	nil	0	11300	20	OK	
			1	01-Aug-07	6	20/64	9000	51.9	43.1	13.0	97.5	0	10.55	3.44	20.0	82	nil	0	11100	20	OK	
			1	10-Sep-07	6	20/64	9400	52.1	43.2	13.0	95.0	0	10.23	3.35	20.0	82	nil	0	6500	20	OK	
			1	01-Oct-07	6	20/64	8800	58.2	48.3	14.6	111.4	0	10.73	3.93	20.0	92	nil	0	5800	20	OK	
			1	02-Nov-07	6	20/64	9050	50.2	41.7	12.6	103.7	0	11.59	3.66	20.0	79	nil	0	5800	20	OK	
			2	11-Nov-07	6	32/64	7800	71.4	59.3	23.8	150.6	0	11.83	5.32	25.0	150	nil	0	4400	25	OK	Choke increased. Test gas exceed the limit. Need to maintain choke at 20/64".
			1	02-Dec-07	6	32/64	8000	74.9	62.2	18.8	154.4	0	11.57	5.45	20.0	118	nil	0	4500	20	OK	
			1	03-Jan-08	6	32/64	9800	70.9	58.9	17.7	142.2	0	11.25	5.02	20.0	112	nil	0	5200	20	OK	
			1	01-Feb-08	6	36/64	7000	52.8	43.8	17.6	117.5	0	12.49	4.15	25.0	111	nil	0	5300	25	REJECT	
			2	01-Feb-08	6	36/64	7000	52.8	43.8	17.6	117.6	0	12.50	4.15	25.0	111	nil	0	5300	25	REJECT	
			3	02-Feb-08	6	36/64	8400	66.2	54.9	22.0	144.2	0	12.23	5.09	25.0	139	nil	0	5300	25	OK	Need to bean down at 32/64" choke for maximum production.
			1	01-Mar-08	6	36/64	8000	69.6	57.8	23.2	158.5	0	12.77	5.60	25.0	146	nil	0	4500	25	OK	
			1	12-Apr-08	6	36/64	7600	61.5	51.1	12.0	169.5	0	15.46	5.99	16.3	76	nil	0	3500	0	OK	
			1	01-May-08	6	36/64	7500	65.2	54.1	21.7	172.4	0	14.83	6.09	25.0	137	nil	0	3300	25	OK	
			1	01-May-08	6	36/64	7500	67.0	55.6	12.5	172.4	0	14.44	6.09	15.7	79	nil	0	3300	25	OK	
			1	02-Jun-08	6	36/64	7600	68.3	56.7	29.2	172.6	0	14.19	6.10	30.0	184	nil	0	1400	0	OK	Water increased rapidly. To monitor closely.
			1	09-Jun-08	6	36/64	2300	72.4	60.1	0.0	82.6	0	6.41	2.92	0.0	0	nil	0	0	0	REJECT	No water figure.
			1	21-Jun-08	6	28/64	8600	63.3	52.6	21.1	152.1	0	13.48	5.37	25.0	133	nil	0	4000	25	OK	
			1	06-Jul-08	6	36/64	7700	47.0	39.0	15.7	167.5	0	19.98	5.92	25.0	99	nil	0	3000	25	RETEST	Tested while production interrupted.
			2	06-Jul-08	6	36/64	7700	47.0	39.0	15.6	183.5	0	19.52	5.77	25.0	98	nil	0	3000	25	RETEST	Tested while production interrupted.
			3	07-Jul-08	6	36/64	10000	59.4	49.3	25.2	90.0	0	8.49	3.18	29.7	158	nil	0	20	25	OK	

Appendix II: Example of Reservoir Fluid Process Overview from Wellhead.



Appendix III: Material Safety Data Sheet (MSDS) for Chendor Crude Oil.

MATERIAL SAFETY DATA SHEET

PRODUCT IDENTIFICATION AND USE		
PRODUCT IDENTIFIER **CENDOR CRUDE OIL**	PIN UN 1267	CLASSIFICATION Class B Div 2, D Div 1A, D Div 2A, D Div 2B 
PRODUCT USE Refinery Feedstock		
MANUFACTURER/SUPPLIER NAME Petrofac (Malaysia - PM304) Limited		PETROFAC HS&E DEPARTMENT Level 50, Tower 2, PETRONAS Twin Towers, KLCC, Kuala Lumpur, 50088 Tel: +603 2382 2700 Fax: +603 2382 2701
ADDRESS		POISON CONTROL CENTRE Universiti Sains Malaysia - Pusat Racun Negara, Penang, Malaysia Tel: ++604-657 2924

COMPOSITION/INFORMATION ON INGREDIENTS

COMPONENT	CAS NUMBER	% (VOLUME)	LD50 (SPECIES & ROUTE)	LC50 (SPECIES & ROUTE)
Crude Oil (Aromatic, Napthenic and Paraffinic)	8002-05-9	> 99	Not available	
Heptanes				
Octanes				
Nonanes				
Hexanes				
Methyl Cyclohexane				

Butane				
Pentane				
1,2,4 Trimethyl Benzene				
Propane				
Cyclohexane				
Xylene				
Benzene				
Toluene				
Methy Cyclopentane				
Ethylbenzene				
Hydrogen Sulfide	7783-06-4	< 0.01	Not available	444 ppm (rat, 4hour)

PHYSICAL INFORMATION		
PHYSICAL STATE Liquid	COLOR AND APPEARANCE Colour ASM D1500-D8.0 (Brown to Black)	ODOR Characteristic Petroleum Odour

VAPOUR PRESSURE (psi)	POUR POINT (Celsius)	EVAPORATION RATE	BOILING POINT (Celsius)	FREEZING POINT (Celsius)
3.85	24 °c	3.85 psi	IBP - 60 °c FBP - 393 °c	-ve 60 °c

14. MERCURY CONCENTRATION	SPECIFIC GRAVITY	COEFFICIENT OF WATER/OIL DISTRIBUTION
2 wt ppb (uop 938)	0.8168	< 0.1 %

FIRE OR EXPLOSION INFORMATION			
FLAMMABLE MATERIAL NO ☐ YES ☑	IF YES, UNDER WHAT CONDITION? In the presence of heat, sparks or flame; and air *Note: Vapours may travel a considerable distance to source of ignition and "flash back" to the crude oil*		
MEANS OF EXTINCTION Foam, Dry Chemical, CO_2 Water may be ineffective to extinguish but water should be used to keep fire -exposed containers cool. If a leak or spill has not ignited, use water spray to disperse the vapours and to protect personnel attempting to stop a leak. Water spray may be used to flush spills away from sources of potential ignition.			
15. FLASHPOINT (Celsius) and METHOD	AUTO IGNITION TEMPERATURE (Celsius) < 25 °c	LOWER FLAMMABLE LIMIT (% BY VOLUME) NO	UPPER FLAMMABLE LIMIT (% BY VOLUME) NO
HAZARDOUS COMBUSTION PRODUCTS			
EXPLOSION DATA:	SENSITIVITY TO MECHANICAL IMPACT YES	SENSITIVITY TO STATIC DISCHARGE YES	
REACTIVITY INFORMATION			
CHEMICALLY STABLE MATERIAL? NO ☐ YES ☑	CONDITIONS OF CHEMICAL INSTABILITY? Stable; Hazardous Polymerisation will not occur.		
INCOMPATIBLE WITH OTHER SUBSTANCES? NO ☐ YES ☑	IF SO, WHICH OTHER SUBSTANCES? Material is stable under normal condition, avoid high temperature, open flame, spark, smoking and other ignition sources. Keep away from strong oxidizers.		

REACTIVE MATERIAL? NO ☑ YES ☐	CONDITIONS OF REACTIVITY? Stable, hazardous polymerisations will not occur.
HAZARDOUS DECOMPOSITION MATERIAL Carbon Monoxide, Carbon Dioxide and None combusted hydrocarbon.	

PRODUCT IDENTIFIER

HEALTH HAZARD INFORMATION		
ROUTES OF ENTRY	**TOXICOLOGICAL PROPERTIES**	**FIRST AID MEASURES**
INHALATION	Oil mist may cause respiratory tract irritation, or, in the case of chronic exposure, chemical pneumonitis. Overexposure may cause weakness, headache, nausea, confusion, blurred vision, drowsiness and other nervous system effects. Greater overexposure may cause dizziness, slurred speech, flushed face, unconsciousness and convulsions. H_2S can cause death. Chronic exposure to Benzene is associated with blood disorders, including leukaemia. Presence of PAHs constitutes a cancer hazard.	If inhaled, remove to fresh air. If not breathing give artificial respiration. If breathing is difficult, give oxygen. Call a physician. (Note: Rescuer must wear positive pressure full face piece, self-contained or supplied air NIOSH approved respirators)

<table>
<tr><td>SKIN ABSORPTION</td><td>Benzene and xylene may be absorbed across in tact skin. They produce the same effects by this route as by inhalation.</td><td>In case of contact, immediately wash skin with soap and water. Wash contaminated clothing before reuse.</td></tr>
<tr><td>INGESTION</td><td>Based on the presence of light hydrocarbon, ingestion of crude oil may cause vomiting; aspiration (breathing) of vomitus into lungs must be avoided as even small quantities may result in aspiration pneumonitis.</td><td>If swallowed do not induce vomiting. Immediately give 2 glasses of water. Never give anything by mouth to an unconscious person. Call physician.</td></tr>
<tr><td>SKIN CONTACT</td><td>Crude oil is presumed to be moderately irritating to the skin. Prolonged and repeated contact can cause dermatitis, folliculitis, oil acne and skin tumour. Contact in hot product may result in thermal burns.</td><td>In case of contact, immediately wash skin with soap and water. Wash contaminated clothing before reuse.</td></tr>
<tr><td>EYE CONTACT</td><td>Crude oil is presumed to be moderately irritating to the eyes. Contact in hot product may result in thermal burns.</td><td>In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Call a physician.</td></tr>
<tr><td colspan="3">EXPOSURE LIMITS</td></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><td>TERATOGENICITY

No information available</td><td colspan="2">RRITANCY

Crude oil is a skin, eye and respiratory tract irritant.

H_2S irritates the eyes and respiratory tract.</td></tr>
</table>

REPRODUCTIVE TOXICITY Some epidemiological evidence that benzene exposure may be associated with reduced male fertility	SENSITIZING PROPERTIES Desensitization of the sense of smell. Thus, the absence of smell should not be taken to indicate the absence of gas.
MUTAGENICITY Positive	CARCINOGENICITY No
CORROSIVITY None	SYNERGISTIC PRODUCTS No

PREVENTIVE MEASURES
PERSONAL PROTECTIVE EQUIPMENT
Wear long sleeve, chemical resistant goggles, safety glass, aprons and gloves.

Petrofac (Malaysia - PM304) Limited and its affiliates assume no responsibility for personal injury or damages whatsoever caused by the material, if reasonable safety procedures are not adhered to as stipulated in this Material Safety Data Sheet. Additionally, Petrofac and its affiliates assume no responsibility for subject injury and/or damage caused by abnormal use of the material, even if reasonable safety procedures are followed. Furthermore, all persons assume the risk in their use of the material.